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Marilyn Sharp, Mary Rosenberger, Joseph Knapik

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Military Performance Division
US Army Research Institute of Environmental Medicine
42 Kansas Street
Natick, MA 01760-5007

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Lifting and lifting and carrying (L-L&C) tasks are the most common physically demanding tasks performed by the Armed Forces of many NATO nations. These tasks contribute to overexertion injuries, particularly low back pain and disability. This review of the literature describes published recommendations for safe loads, the use of teamwork to reduce the load, equations used to predict the energy cost of L-L&C tasks, methods used by NATO nations to evaluate L-L&C performance and training methods to improve L-L&C task performance

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CHAPTER 5 - COMMON MILITARY TASK: MATERIALS HANDLING

Marilyn Sharp[1], Mary Rosenberger[1], Joseph Knapik[2]

Department of the Army
[1]US Army Research Institute of Environmental Medicine
Building 42, Kansas Street
Natick, MA 01760-5007 USA

[2]US Army Center for Health Promotion and Preventive Medicine
1570 Stark Road
Aberdeen Proving Ground, MD 21010 USA

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5.1 INTRODUCTION

5.1.1 Definition of manual materials handling

Manual materials handling (MMH) can be defined as the movement of objects, vertically or horizontally, from one location to another using the body, particularly the hands. This is accomplished through lifting, lifting and carrying, holding, pushing and pulling objects. The manual movement of materials is the most common physically demanding aspect of most non-sedentary occupations, both military and civilian. Lifting and lifting and carrying (L-L&C) constitute the most common physically demanding task performed by the Canadian, US and UK Armies (44, 97, 121, 122). Although MMH tasks include pushing and pulling objects, the focus of this chapter will be on non-mechanized lifting and lifting and carrying objects, as these types of tasks are the most commonly performed by soldiers.

Both military and civilian studies have focused on manual materials handling from three different disciplines. Biomechanical literature focuses specifically on how the lifting and carrying affect loads placed on the lower spine, where most injuries occur. Physiological literature focuses on understanding fatigue associated with the energy cost of lifting and carrying tasks. Psychophysical techniques include understanding the perception of fatigue as well as the load someone would chose to handle during a work day given a work rate.

5.1.2 Injuries during manual material handling

Heavy L-L&C has long been associated with occupational injury, particularly with lower back disorders (17, 18, 25, 37, 65, 73, 128). Injury rates from private and public sectors outline the magnitude of injury problems with regard to overexertion in lifting. Overexertion in lifting accounted for 17% of all injuries involving disability, with another 28% of injuries caused by other types of overexertion (wielding, throwing, holding, carrying, pushing and pulling). All types of overexertion combined account for ~24% of lost work time. Men suffered most of the injuries in private industry, and also took longer to recover from work-related injuries than women (77).

The back is the most consistently injured body part. Data from 1994 indicates that a quarter of all workplace injuries are to the back (77). Back injuries account for 27-28% of injuries involving disability, and 11% of lost work time. *"Injuries to the lumbar region of the back were the most numerous in all US industries." (p. 133)* (78). In the US Army from 1990 to 1994, back-related problems accounted for 20% of all physical disability cases resulting in discharges from service (22). Data from the Defence Medical Surveillance System indicates that disorders of the back (International Classification of Diseases, Version 9 code 724) had the second highest number of outpatient visits from 1998-2005 resulting in 232 visits/1000 person-years (unspecified disorders of joints ranks number one at 253 visits/1000 person-years) [data obtained from on-line access of Defense Medical Epidemiology Database, May 2006, amsa.army.mil]. Most back injuries involve sprains and strains. In the civilian sector, approximately 70% of back injuries are associated with overexertion in lifting. Males, workers between the ages of 25 and 34, and White, non-Hispanic workers all had higher injury rates to the lower back than other groups (78).

5.1.3 Variability of MMH tasks

The important task variables for L-L&C tasks are the load lifted/carried, the height from and to which the object is lifted, the frequency with which the object is lifted, the distance an object is carried, team size (whether the task is performed by an individual or a team of soldiers), and the dimensions and characteristics of the object moved. L-L&C tasks vary greatly and have the potential to stress any of the body's three energy

producing systems. L-L&C tasks can be purely strength demanding, stressing the ATP-CP system, as in the case of a single heavy lift. Short duration L-L&C tasks, such as lifting and carrying a heavy object for 30-seconds, stress the anaerobic system. L-L&C tasks that are repetitive in nature, and last more than a few minutes are aerobically demanding, as in the case of unloading a number of boxes from pallets.

5.2 DESCRIPTION OF MILITARY MANUAL MATERIAL HANDLING TASKS

5.2.1 Recommended limits or standards set for L-L&C Tasks

There are industrial load limits (Germany, Greece, Austria, Finland) or ergonomics guidelines (USA, UK, Netherlands) for many NATO countries (82). The best known guideline in the United States is the National Institute for Occupational Safety and Health Work Practices Guideline (144). The equation provided in the guideline can be used to evaluate the safety of a lifting task and takes numerous task variables into account (lift starting and ending height, load, frequency, reach, handles, task symmetry, etc). It is a useful equation to determine the effect of changes in task variables. The NIOSH equation was evaluated and modified by Hidalgo et al (41) to develop a comprehensive lifting model. Two new lifting indices were developed: The Relative Lifting Safety Index, which is used to evaluate a lifting task for a group of workers, and the Personal Lifting Safety Index, which is used to evaluate the relative safety of a lifting task for an individual worker (41). These indices consider factors in addition to those considered by the NIOSH lifting index, particularly heat stress, body weight, gender and age. Some of the load modifiers were adjusted to include more recent data. The equations for calculating NIOSH or modified NIOSH recommended loads can be found in Appendix A.

The US Army sets limits on the loads to be lifted by soldiers during the design of new equipment in Military Standard 1472F(4). The standard sets an absolute maximum load of 39.5 kg to be lifted by one male soldier using two hands from the floor to a waist high surface. This load is decreased if women will be handling the object (20 kg), if the object is to be lifted to a greater height (25.4 kg), if the object is lifted repetitively, or if the object is not compact or extends more than 30 cm away from the body. The limit for lifting from the floor, carrying an object 10 m or less, and replacing the object on the floor is 37.2 kg for men and 19 kg for women. Again, these allowable loads are decreased for repetitive tasks, loads lifted to greater than waist height, and unwieldy objects.

The UK Ministry of Defence has published design guidelines, with permissible loads located at various vertical and horizontal distances from the body for the 97th and 3rd percentile male and female for lifting rates of 1 lift$\cdot$min^{-1} and 2 lifts$\cdot$hour^{-1}(3). These limits are reduced for larger or bulkier loads, loads without handles, higher lifting frequencies, awkward body positions, etc. The goal of these limits and guidelines is to ensure that most soldiers will be able to handle the equipment that is being designed. Unfortunately, for most of these international and military standards, much of the equipment currently in use exceeds these standards, so there is a discrepancy between what is recommended by the standards and what is actually required of the soldier.

5.2.2 Physical characteristics of objects handled by military personnel

Physical characteristics of the objects handled vary greatly in size, shape, existence or location of handles, and fluidity. Mital & Ayoub (80) recommended that objects lifted be compact, stable, not extend more than 50 cm away from the body, and that the distance between the hands be kept to a minimum. Handles have been shown to increase maximal lifting capacity by 4%-30% (82). US Army Military Standard 1472F (4) identifies the optimal object for lifting as *"an object with uniform mass distribution and a compact size not exceeding*

46 cm high, 46 cm wide and 30 cm deep (away from the lifter)", pg 139. It also assumes the object will have handles, and they will be located at half the object height and 15 cm deep. Not all objects lifted by military personnel meet these specifications. In their review of UK Army MMH tasks, Rayson (97, 101) report that while most objects had good hand coupling, *"A number of examples of large and variable shaped objects were measured which included various missiles, generators and scanners, camouflage nets etc., which compelled unusual methods of handling. Other objects were either asymmetrical in load distribution (generators, missiles, drawbars etc.) or had unstable loads (camouflage nets, fuel cans, food pots etc) thereby reducing performance" pg 396.*

Most of the research in the literature on L-L&C capabilities examined box lifting capacity. While it is convenient for research purposes to study box lifting performance, or Olympic weight bar lifting, it should be noted that these investigations represent an artificial environment and reflect the maximum performance possible. The measured L-L&C capabilities must be adjusted downward when handling sub-optimal configuration objects, such as sand bags, liquids (51), camouflage netting (91) or injured soldiers (106, 107).

5.2.3 Scope of military lifting and lifting and carrying tasks

5.2.3.1 Loads lifted and carried

Rayson et al (97, 101) and Sharp et al (121, 122) have described the scope of L-L&C task demands for the United Kingdom (UK) and United States (US) Armies, respectively. Although the methodologies of the two studies differed, the results were similar. L-L&C were the most frequently performed physically demanding tasks. Figure 1 is a frequency diagram of the loads lifted and carried by US and UK Army soldiers. The US Army tasks were broken down into Lifting and Lifting and Carrying categories, while the UK Army tasks included both. Although the frequency distributions were similar, it appears British soldiers have a greater percentage of tasks in the highest load category. In the representative sample of tasks examined, the loads lifted and carried by US soldiers range from 4.5 to 85 kg/person as compared to 10 to 110 kg for UK soldiers.

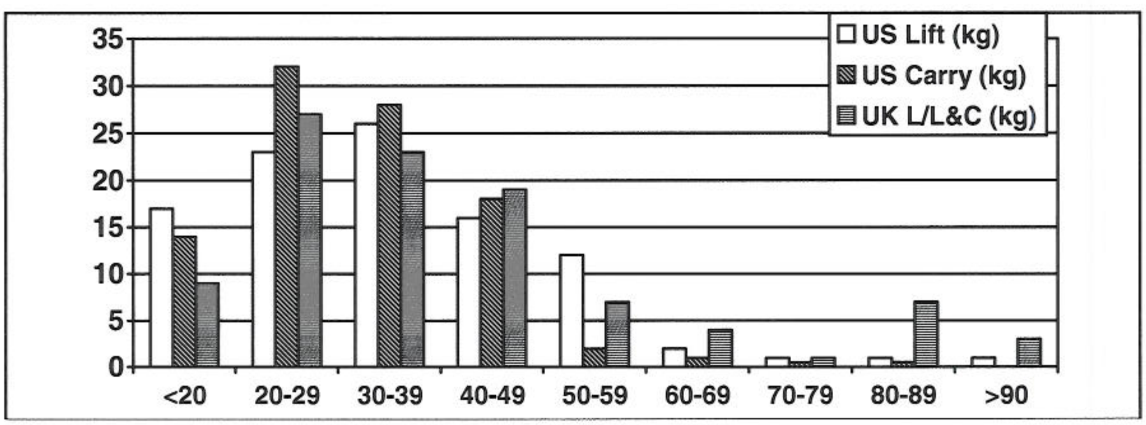

Figure 1: Frequency distribution of loads handled by US and UK soldiers

5.2.3.2 Heights for loads lifted and carried.

Eighty-nine percent of the loads handled by US soldiers are lifted and carried from floor to waist height or below, 9.5% are lifted between waist and shoulder height, and only 1.7% are lifted and carried above shoulder height (121). Not only do the loads for the British Army tasks tend to be heavier, the objects tend to be lifted higher. Seventy percent of British Army lifting tasks are initiated at floor level. The loads were lifted to waist height (0.8 - 1.3 m) in 57% of the tasks, to shoulder height (1.4-1.6 m) in 28% of the tasks and above shoulder height (>1.6m) in 15% of the tasks (101).

5.2.3.3 Carry distances for loads lifted and carried.

More than half the lift and carry tasks performed by both US and UK soldiers involve carries of 10 m or less, and the majority (>80%) are carries of 50 m or less (Figure 2). Loads in excess of 45 kg are carried an average distance of 11 m (range=1-34 m), however, there is no relationship ($r=-0.02$, $p=0.74$) between the weight of the load carried and the distance it is carried (97, 121).

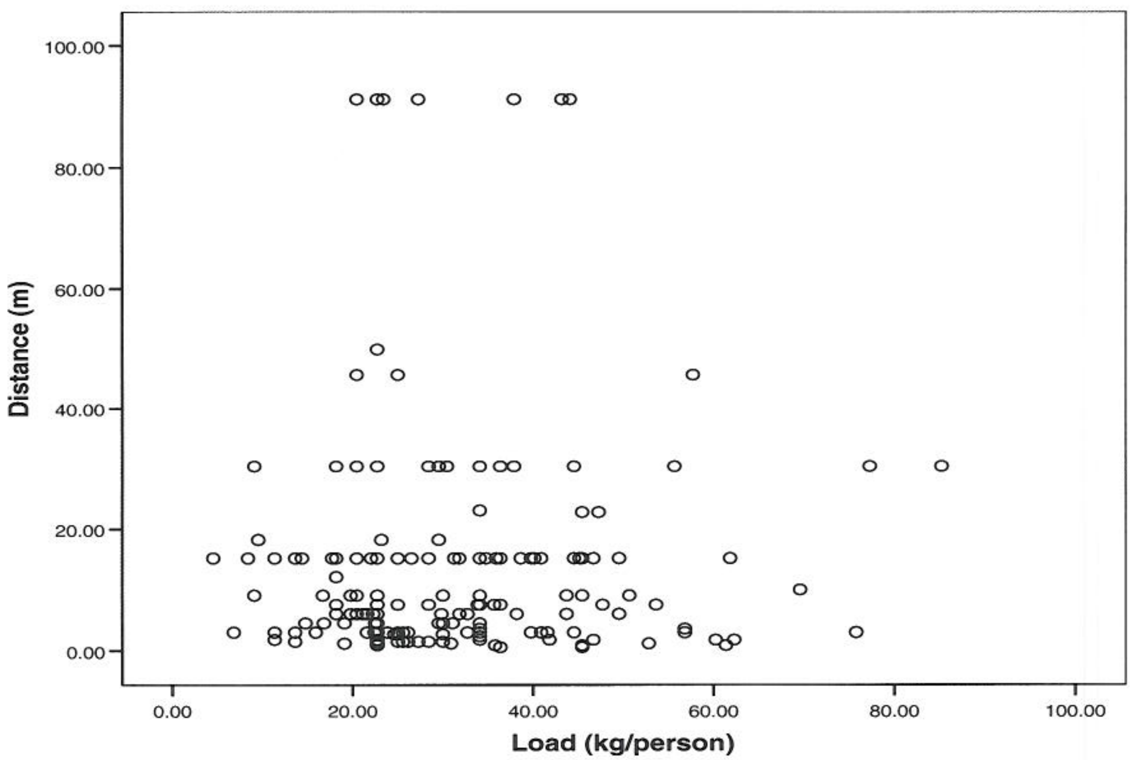

Figure 2: Relationship between load and distance carried for US Army lifting and carrying tasks.

5.2.3.4 Scope of US Army lifting/lowering tasks

The mean load for all US Army lifting/lowering tasks was 35.5 ± 17.0 kgs. The 25th, 50th, and 75th percentile loads calculated were 22.7 kgs, 34.1 kgs, and 48.9 kgs, respectively. The mean load lifted to each vertical lift height was: 44.1 ± 13.6 kgs to knuckle height (n=27), 34.0 ± 19.0 kgs to waist height (n=36), 28.2 ± 13.5 kgs to shoulder height (n=25), and 35.5 ± 18.9 kgs above shoulder height (n=4) (121).

5.2.4 Scope of military team tasks

The mass or size of the load of many manual materials handling (MMH) tasks mandates the use of multiple-person teams. Examples of these tasks are moving bridge construction parts, carrying injured persons on stretchers and setting up camouflage. The majority of research on team lifting performance has concentrated on either a single maximum lift (48-50, 109, 123, 125) or the maximum acceptable weight of load (MAWL) for repetitive lifting (23, 45, 95, 113, 123). The team based task that has received the most scrutiny is patient handling (57, 59, 67, 73, 106-108, 138).

5.2.4.1 Military team lifting limits

U.S. Military Standard 1472 F (4) provides recommendations to be used in the design of equipment for the U.S. Armed Forces and makes reference to team lifting. For two-person teams lifting from floor level to 91 cm, the standard recommends doubling the one-person load (79 kg for two men, 40 kg for two women), and a maximum of 75% of the one-person value can be added for each additional lifter beyond two. The Military Occupational Classification Structure (20) describes the physical demands of all U.S. Army jobs, and provides many instances where these standards are exceeded. One example is the medical specialist who treats injured soldiers and transports them on a hand-held stretcher in four person teams. Based on Military Standard 1472 F, four women should not lift patients weighing more than 70 kg. The fiftieth percentile male soldier weighs 78 kg, while the fiftieth percentile female soldier weighs 62 kg (36). Based on this standard, four female soldiers could safely lift the average female soldier, but should not carry the average male soldier.

5.2.4.2 Assessment of team lifting

The one repetition maximum (1RM) isometric and isokinetic strength of teams of two and three men and two and three women (49, 50) and the 1RM dynamic lifting strength of two-, three- and four-person teams of men, women and mixed-gender teams has been studied (48, 125). All these studies involved a simple lift/lower or isometric (simulated) lift under optimal conditions, using small samples of young healthy individuals. Table 1 presents a summary of the 1RM team lifting data from U.S. Army Soldiers (125). The one person lift was a deadlift of an Olympic weight bar. A square shaped frame of four Olympic weight bars was used for two- and four-person lifting and a triangular shaped frame used for three-person lifts.

Table 1: Mean ± standard deviation for maximum team-lifting strength (kg) by team size and gender (numbers in parentheses indicates n of sample or number of teams included in mean)

Team size	Men	Women	Mixed-gender
Individual	137.0 ± 22.1 (23)	84.7 ± 14.2 (17)	
Two-person	252.9 ± 32.8[a](26)	155.8 ± 15.7[b](24)	183.5 ± 24.1[b,c](25)
Three-person	345.1 ± 39.5[d](18)	214.6 ± 17.6[c](18)	262.3 ± 33.5[a](36)
Four-person	493.2 ± 65.3[e](20)	307.7 ± 31.4[f](19)	397.3 ± 37.1[g](21)

[a-g] Letters indicate significant differences between means ($p<0.05$) for team lifting.

To examine the relationship between the sum of the individual lifting strengths of team members and team-lifting strength, the percentage of the sum of individual strength represented by the team strength (% sum) is calculated:

Equation 1: Percent of the sum of individual strengths in team lifting

$$\%sum = \left(\frac{team\ strength}{sum\ of\ individual\ strengths} \right) * 100$$

With the exception of isometric arm lift strength, the team 1RM lifting strength is less than the sum of the individual 1RM lifting strengths by 10% to 40%, or a % sum of 60% to 90%. The % sum varies with the team gender and the specific lifting task. During dynamic maximal lifting (isotonic lifting), the % sum was significantly greater for single gender teams (87% for men; 91% for women) than for mixed gender teams (80%) when lifting in teams of two, three or four (125). Table 2 lists the % sum for three modes of lifting by gender and team size. Teams of men tend to lift heavier loads than mixed-gender teams, while teams of women tend to lift lighter loads than the other gender combinations(126). The greater the combined strength of a multi-person team the greater the load that is lifted by the team. This has been shown to be true, regardless of differences in stature (95, 125). Table 2 provides a range of several types of team lifting tasks to include deadlift of an Olympic weight bar (125), lifting a load mounted between two poles-similar to lifting a stretcher (95), box lifting (48), and isometric and isokinetic upward pulling on a bar (49, 50). If norms are available for an individual lifting task, Table 2 can be used to estimate the load for various team sizes using the lifting task most similar to that in question.

Table 2: Percentage of the sum of individual lifting strengths represented by the team lifting strength (% sum) by lifting mode, team gender and size.

	Team Size	Men	Women	Mixed-Gender
Dynamic	2-person	87.5 - 89.8 [1-3]	91.0 – 95.6 [1-3]	69.8 - 79.7 [2,3]
	3-person	85.0 [3]	90.9 [3]	78.5 [3]
	4-person	86.0 [3]	90.3 [3]	83.7 [3]
Isometric	2-person	94.1 [4]	79.1 [5]	
	3-person	88.6 [4]	87.0 [5]	
Isokinetic	2-person	66.5 [4]	70.5 [5]	
	3-person	60.3 [4]	72.8 [5]	

[1] Karwowski 1988, [2] Pinder, 1998, [3] Sharp et al, 1997, [4] Karwowski and Mital, 1986; and [5] Karwowski and Pongpantanasuegsa, 1988.

Litter carriage is a common military team task that has been studied, often with the focus on reducing the demands of the task (58, 59, 106, 107). As in the study by Stevenson (132) a two person litter carriage task is often tested with the rear of the litter supported, and one person performing the task (58, 59, 106, 107). The US Army uses a four person stretcher carry over an obstacle course during conduct of the Army Field Medic Training and for the Expert Field Medic Badge. As might be expected, handgrip strength has been cited as an important predictor of litter carriage performance, particularly for extended carrying (57, 108, 143). Time in carrying a litter can be considerably extended by placing more of the load on the torso (as opposed to the hands) through a variety of straps and harnesses (57, 106, 107)

5.2.4.3 Maximum acceptable weight of lift for teams

In addition to maximum lifting strength, the load a team finds acceptable for prolonged periods of repetitive team lifting is important. The load acceptable to 95% of the working population has been used to set limits for safe materials handling in industrial settings. The MAWL is defined as the load a person is willing to work with under a given set of task conditions. For example, an individual may be asked to determine the MAWL for an 8 hour work day when lifting a box from the floor to a 70 cm high table at the rate of 3 times per minute. The person is given a box that is either too heavy or too light and asked to perform the defined task for a 20 min period. The individual then adds or subtracts weight from the box until it is judged acceptable. The load is adjusted by the individual so that he/she does not become overtired, overheated or out of breath. When working in teams, both team members must agree on the load adjustments and final load.

Unlike the 1RM for team lifting, the MAWL for material handling in teams tends to be equal to or greater than the sum of individual MAWLs (%sum=98%-140%) (23, 45). In pairs of individuals with large strength differences, the lower strength person tends to have a slightly higher heart rate and works at a slightly greater percentage of their physical work capacity than the higher strength person, compared to when working alone. Because they tend to work harder, the weaker individual will fatigue faster over a prolonged exercise period and may be at an increased risk for injury during team MMH tasks (23). This is reflected in the Rating of Perceived Exertion provided by the lower strength individual. Although individuals of fairly equal strength tend to lift as much or more than the sum of their individually selected loads, they tend to perceive the load as easier than when performing the same task alone (123). This may be due to the different lifting technique used when working alone versus working in a team.

While the team MAWL is equal to or greater than the sum of the individual MAWLs, this is not true of 1RM team lifts. Task differences may be the source of these opposing results. The 1RM team lift is a one-time, maximum effort involving little decision making. The team is either physically able or unable to lift the load. In contrast, the MAWL is typically a repetitive, submaximal self-selected load, with the procedure allowing time for reflection and adjustment. The individual or team must estimate the load they are willing to handle for an extended period. Because there is a subjective element to MAWL selection, personality interactions may influence the team MAWL while not affecting the 1RM lift. Some studies have shown Type A individuals work at a higher percentage of their aerobic capacity, and are able to determine their MAWL in a shorter period of time than Type B individuals (112, 113). The higher MAWL for teams than for the sum of individuals making up the team might be an expression of competitive behaviour or a higher level of arousal. Individuals may be more motivated to select heavier loads when working in teams than when working alone for social reasons. This may affect the risk of injury in team versus individual tasks.

Lifting frequency may also have an effect on the % sum obtained during a MAWL as compared to that obtained during a 1RM. Studies that used an infrequent lifting rate, one lift and lower per hour or less, reported % sums of less than 100% (48, 95). Those studies using a more frequent lifting rate reported % sums approximately equal to or greater than 100% (23, 45, 123). These low frequency MAWL studies seem

to be more comparable to studies of 1RM team lifting, than to studies of team MAWL at higher lifting frequencies.

5.2.4.4 Military team task loads and gender differences

In the U.S. and British Armies, the most commonly occurring team size is a two-person team, followed by four- and then three-person teams (97, 121). In the absence of documentation, it is assumed two-person teams are the most common team size in industrial team tasks as well. The UK Army uses teamwork for 66% of the physically demanding L-L&C tasks(101). Forty eight percent of the US Army L&C tasks and 53% of the lifting/lowering tasks involved teamwork. A survey of US Army MOS determined that the average load for a two-person L&C task was 59 kg. This is similar to the mean load of 60 kg selected by teams of two-soldiers during a study of the maximum acceptable weight load (MAWL) for repetitive lifting and carrying (123). Teams of two men selected a load of 72 kg, teams of two women selected a load of 46 kg (22% less than the average US Army two-person lift and carry task), and mixed gender teams (one man and one woman) selected a load of 57 kg (123). As these gender specific figures represent the mean of the soldiers studied, there are teams within all three gender groups that would experience difficulty with the average US Army two-person lift and carry task, but teams of two women and mixed-gender teams would have the most difficulty completing the team L&C tasks.

In

Table 3 the median US Army loads for multi-person lifting tasks (121) are listed in column 1 (Task Requirement) as well as the 1-RM load lifted by individual women and teams of two to four women (column 2) (125). The third column shows the task requirement as a percentage of the maximum load lifted by teams of women (% Women's Maximum). The percent maximum load was determined by:

Equation 2: Determining percent of maximum workload

$$\%\max = \left(\frac{Task\ Requirement}{Load\ Lifted\ by\ Women} \right) * 100$$

The loads were lifted to knuckle height, under optimum conditions using a device similar to an Olympic weight lifting bar (125). The loads were not carried, but rather lifted then immediately placed back on the ground. 1RM loads in Table 3 represent the maximum that could be lifted (not carried) by teams of healthy young female soldiers. As teams of all-women tended to have lower maximum lifting strength than mixed-gender or all-men teams, the percentage would be expected to be lower (easier to lift) for all-men and mixed-gender teams. Doolittle, et al. (21) recommends that an individual not lift more than 20% of his/her maximum for repetitive efforts, and not more than 75% for occasional efforts. Based on this, the typical loads encountered by teams of US Army soldiers do not appear to be too great to be lifted occasionally at least to knuckle height.

Table 3: US Army lifting task requirements and female soldier lifting capability by team size.

Team Size (persons)	Task Requirement (kg/person) [1]	1RM for Teams of Women (kg) [2]	% Women's Maximum
One	33	85	39
Two	77	156	50
Three	57	215	27
Four	62	308	20

[1]Sharp et al, (121)

[2]Sharp et al, (125)

5.2.4.5 Prediction of team manual materials handling performance

Several published regression equations can be used to predict team manual materials handling performance. Dependent variables have included measures of muscle strength (1RM lifting strength, and individual MAWL), anthropometric characteristics (flexed bicep, abdominal, and chest circumference), and gender (all-male, all-female, or mixed-gender teams)(23, 81, 95, 126). These equations were able to account for between 35% - 98% of the variance in team MMH performance, but most reported a relatively large standard error of the estimate, making them of limited practical use.

5.3 PHYSIOLOGICAL REQUIREMENTS

A number of factors determine the physiological demands of a repetitive L-L&C task. These include the body position, lifting technique, physical characteristics of the load (most importantly the mass), starting height of the lift, vertical travel distance, frequency of lifting, and number of repetitions performed. In addition, environmental factors such as temperature and humidity, and clothing worn, can influence the physiological demands of a L-L&C task.

5.3.1 Technique

Lifting technique will greatly influence the energy expended, particularly during a prolonged repetitive lifting or lifting and carrying task (5, 27, 29, 38, 66, 139, 145). Although a bent knee, straight back lifting technique is often recommended for safety, this technique is rarely used during repetitive lifting. This form may be maintained during an occasional heavy lift, and is particularly useful when the load fits between the knees (82). However, squat lifting technique elicits a higher energy cost due to the work of moving one's body mass

up and down. For repetitive lifting, a freestyle or semi-stooped lift is typically self-selected as the most energy efficient.

5.3.2 Object/task variables

The heavier the load lifted, the greater the work done, and the greater the metabolic requirement to complete the task (5, 9, 28, 47, 70, 94, 117). The starting height of the lift, in conjunction with the lifting technique will determine the degree to which the body center of mass must be displaced to complete the lift. If the same load is lifted a vertical distance of 0.5 m starting from the floor or from knuckle height, the knuckle height lift will involve less movement of the body center of mass, and will therefore incur a lower metabolic cost. All other factors being equal, the greater the vertical travel distance, the greater the work done, and the greater the metabolic cost of a L-L&C task. Increases in the frequency of lifting produce increases in the metabolic cost of repetitive lifting (43, 76, 94). These increases tend to be linear at lower percentages of maximal oxygen uptake (<50%). As the object size increases, so does the energy cost for repetitive L-L&C (80).

Total energy cost is related to the rate of work, number of repetitions and total duration of L-L&C tasks. The longer the task duration, the lower the percent of maximal energy expenditure that can be maintained. The intensity and durations of most soldiering tasks are not well defined. For example, during a re-supply, soldiers move materials until the weapon or transport vehicle is full. This may take anywhere from a few minutes to several hours. If the vehicle has been recently re-supplied, fewer supplies will be needed and the task will be accomplished more rapidly. In peacetime, re-supply can be a self-paced activity. In some operationally hostile environments, Soldiers must accomplish the task as rapidly as possible. All these factors influence the metabolic requirements of the task. There are a number of predictive equations to determine the energy cost of L-L&C tasks and some are listed in Table 4 (10, 26, 28, 29, 79, 96, 135, 136).

Table 4: Prediction equations for energy expenditure during lifting exercise

Type	Height	Energy Expenditure Equation (kcal/min)	Reference
Stoop Lift		E=0.0109 BW + (0.0012 BW + 0.0052 L + 0.0028 S x L) f	Garg (1976)*
Squat Lift		E=0.0109 BW + (0.0019 BW + 0.0081 L + 0.0023 S x L) f	Garg (1976)*
Arm Lift		E=0.0109 BW + (0.0002 BW + 0.0103 L - 0.0017 S x L) f	Garg (1976)*
Stoop Lift	$h_1 < h_2 \leq .81$	$E=10^{-2}$[0.325 BW (0.81- h_1) + (1.41L + 0.76S x L) (h_2- h_1)]	Garg et al. (1978)*
Squat Lift	$h_1 < h_2 \leq .81$	$E=10^{-2}$ [0.514 BW (0.81- h_1) + (2.19L + 0.62S x L) (h_2- h_1)]	Garg et al. (1978)*
One hand lift	$h_1 < h_2 \leq .81$	$E=10^{-2}$ [0.352 BW (0.81- h_1) + 3.03L (h_2- h_1)]	Garg et al. (1978)*
Arm lift	$.81 < h_1 < h_2$	$E=10^{-2}$ [0.062 BW (h_2-0.81) + (3.19L + 0.52S x L) (h_2- h_1)]	Garg et al. (1978)*
Stoop lower	$h_1 < h_2 < 0.81$	$E=10^{-2}$ [0.268 BW (0.81- h_1) + 0.675L (h_2-h_1) + 5.22S (0.81- h_1)]	Garg et al. (1978)*
Squat lower	$h_1 < h_2 \leq .81$	$E=10^{-2}$ [0.511 BW (0.81- h_1) + 0.701L (h_2- h_1)]	Garg et al. (1978)*
Arm Lower	$.81 < h_1 < h_2$	$E=10^{-2}$ [0.093 BW (h_2-0.81) + (1.02L + 0.37S x L) (h_2- h_1)]	Garg et al. (1978)*
Carry	At arms length at sides	$E=10^{-2}$ [80 + 2.43 BW x V^2 + 4.63L x V^2 + 4.62L + 0.379 (L + BW) G x V]t	Garg et al. (1978)*
Carry	Held against thighs or waist	$E=10^{-2}$ [68 + 2.54 BW x V^2 + 4.08L x V^2 + 11.4L + 0.379 (L + BW) G x V]t	Garg et al. (1978)*
Lifting and/or Carrying	From 75cm-150cm	VO_2 = 0.1809 + [(BW + L) x (2.6112 x (BW + L)92.594 x D x H) + F x (318.16 x L + 7.9185 x BW x D + 49.1565 x L x D)] x 10^{-5} + 2.2956 x WID/L	Taboun & Dutta (1989)**
Lifting and/or Carrying	From floor-150 cm	VO_2 = 0.0738 + [(BW + L) x (3.9918 x (BW + L) + 61.226 x D x H) + L x F x (424.131 + 81.926 x D)] x 10^{-5} + 3.851 x WID/L	Taboun & Dutta (1989)**
Intermittent Carry	Waist Height	VO_2 = 36.3 – (1.74W) – (1.76D) – (7.17F) + (0.027W^2) + (0.014WD) + (0.196WF) + (0.783DF)	Randle et al. (1989) ***

* E= energy expenditure (kcal/min), BW = body weight (lbs), L= load weight (lbs), S=Sex (female=0, male=1), f=frequency (lifts/min), h_1 = Vertical height from floor (m) at the lower end of the lift or lower, h_2= vertical height from floor (m) at the upper end of the lift or lower

** VO_2 = oxygen uptake (l/min), BW = body weight (kg), L = load (kg), F = frequency (lifts/min), D = carrying distance (m), H = height range of lift (m) and WID = box width along the sagittal plane (m)

*** VO_2 = oxygen uptake (mL/kg/min), W = load weight (kg), D = carrying distance (m), and F = frequency (carrys/min)

There are a number of reports in the literature indicating the energy cost of soldiers performing various simulated L-L&C tasks (15, 70, 85, 92, 97, 106, 118, 119, 124). A summary of energy cost of soldier tasks measured in a laboratory setting are found in Table 5 for women and Table 6 for men. Rayson (97) measured the cardiovascular requirements of UK soldiers performing actual L-L&C tasks (not simulated tasks) of longer duration. Soldiers worked at 55 to 88% of their maximum heart rate, with 59% of the tasks in the 70 to 79% maximum heart rate range. The rate of oxygen uptake ranged between 1.16 and 2.92 $l \cdot min^{-1}$, with 80% of the tasks falling within the 1.5 to 2.5 $l \cdot min^{-1}$ range. Due to the difficulty of identifying the required lifting rate, the aerobically demanding L-L&C tasks were self-paced during the metabolic measurements. As mentioned above, the intensity of MMH task performance of soldiers is often determined by the situation. For this

reason, it is difficult to accurately characterize the typical cardiovascular strain of soldiers during MMH tasks because an acceptable level of intensity and duration of task performance has not been operationally defined.

Table 5: Energy cost of soldier MMH tasks performed by women (92)

Task	Load (kg)	Frequency (lifts/min)	Height or Distance (m)	VO_2 (L/min)	VO_2 (ml/kg)	VO_2 max (%)	VE (L/min)	HR (b/min)
Lift	22.7	1	1.32	0.46	7.8	17.8	15.1	100
	22.7	2	1.32	0.67	11.5	26.2	20.8	120
	22.7	4	1.32	1.02	18	41	29.3	146
Lift/Lower	25	0.25	1.32	0.39	6.2	13.8	13.4	87
	25	1	1.32	0.63	12.3	26.4	20	120
	22.7	6	1.32	1.14	18.2	41.1	32.1	127
Lift and Carry	25	0.5	15	0.42	8.2	17.7	14.3	103
	25	1	15	0.6	11.5	24.6	19.7	115
	18	1	6.1	0.57	9.9	22.7	18.1	108
	27.3	1	4	0.66	10.7	23.9	22.7	113
	6.8	0.5	15	0.43	6.8	15.6	16	94
	25	2	15	0.85	13.7	30.6	28.4	124
	18.2	1	9	0.87	14	31.5	26.2	114
	27.2	3	30	2.03	33.1	74.1	71.3	170
	25	3	15	1.25	20.8	48	40.2	157

Table 6: Energy cost of soldier MMH tasks performed by men

Task	Load (kg)	Freq (/min)	Height or Distance (m)	VO_2 (L/min)	VO_2 (ml/kg/min)	VO_2 max (%)	VE (L/min)	HR (b/min)	Workrate (W)
Lift[1]	22.7	4	1.32	1.14	15.4	28.8	29.6	119	394
	22.7	2	1.32	0.74	9.8	19.2	20.9	106	256
	22.7	1	1.32	0.58	7.5	14.9	18.1	95	201
Lift/Lower[1]	22.7	6	1.32	1.33	16.5	30.3	33.9	119	460
	25	0.25	1.32	0.54	6.7	12.2	16.1	87	187
	25	1	1.32	0.7	9.5	17.9	20.4	100	246
Lift and Carry[1]	25	0.5	15	0.49	6.7	12.7	15.3	88	170
	25	1	15	0.63	8.5	16	18.3	97	242
	36	1	6.1	0.86	11	21.4	24.4	104	298
	18	1	6.1	0.71	9.1	18	20.5	98	247
	27.3	1	4	0.78	9.6	17.7	23	98	270
	6.8	0.5	15	0.6	7.4	13.7	19.3	89	208
	45	2	5	0.82	11	21.1	22.7	104	284
	45	4	5	1.29	17.4	33.5	37.1	130	446
	45	3	5	1.07	14	26.8	31.3	115	370
	25	2	15	1.01	12.4	23	27.5	104	349
	18.2	1	9	1.11	13.7	25.1	29	109	384
	27.2	4	30	3.36	41.4	76.2	104.8	167	1162
	25	4	15	1.76	22.9	44.8	46.4	135	609
Lift, Control[2]		8.2	1.4		38.4	86.9		169.6	
Lift, Trained[2]		9.2	1.4		38.1	88		182.8	
Lift/Lower[3]	26.4	4	40% Subject Height	0.75			17.3	101.5	
	26.4	5.3	40% Subject Height	0.75			17.4	102.9	
	24.1	4.8	40% Subject Height	0.71			16	98.4	
Lifting[4]	22.4	8	40% Subject Height	1.55	20.5	41.4	42.8	131	1.24
	22.4	10	40% Subject Height	1.79	23.9	47.7	51.2	143	1.54
	22.4	12	40% Subject Height	1.86	25	49.5	57	150	1.86
	44.8	4	40% Subject Height	1.41	18.6	37.6	38.1	123	1.24
	44.8	6	40% Subject Height	1.79	23.7	47.6	54	147	1.86
	44.8	8	40% Subject Height	1.98	27.1	53.9	61.7	160	2.48
	67.2	2	40% Subject Height	1.17	15.3	31	36.5	122	0.93
	67.2	3	40% Subject Height	1.52	20	40.3	45.8	141	1.4
	67.2	4	40% Subject Height	1.91	25.1	50.9	60.5	153	1.86

* 1: Patton, 1995; 2: Sharp et al, 1993; 3: Nicholson & Legg, 1986; 4: Legg, 1984

5.3.3 Physiological limits for repetitive L-L&C tasks

The recommended upper limits for prolonged performance of aerobically-demanding, repetitive L-L&C tasks typically ranges from 28% up to 35% cycle ergometer VO_2max for an 8 hour day (6, 46, 70, 72, 93). Garg (28) recommends that the exercise intensity of repetitive L-L&C tasks not exceed 50% VO_2max (treadmill or cycle ergometer) for one hour, 40% VO_2max for 2 hours or 30% VO_2max for 8 hours to avoid fatigue.

5.4 EVALUATION OF L-L&C PERFORMANCE

There are several approaches for evaluating L-L&C performance. The maximum performance capability of the individual, such as a 1RM can be examined, or a minimal performance standard can be set and soldiers tested to determine if they are capable of meeting that standard. Several of the NATO allies have conducted job analyses of physically demanding soldiering occupations and have developed CMTs representing the most common lifting or lifting and carrying tasks. Many of these tests were designed as the first step to develop pre-assignment screening tests to place service members into physically appropriate jobs. Knapik et al (62) has recently published a thorough review of the pre-assignment screening tests used by many of the NATO Forces. The types of tests pertaining to L-L&C used in the literature, as well as the tests used by the NATO Forces will be briefly reviewed here.

5.4.1 One-repetition maximum (1RM) lift

Tests of lifting strength are typically a one-repetition maximum lift (1RM) of a box to a given height. In most military applications, it is the height of the standard supply transport vehicle (40, 103, 114, 114). Alternatively, the lift height can be based on body landmarks, such as floor to knuckle height or floor to shoulder height (12). Physical fitness measurements found to be predictive of 1RM lifting strength include fat free mass (12, 98, 114, 137), isometric 38 cm upright pull (114, 137) , isometric back extension strength (98), incremental lift machine (12, 98, 137), vertical jump, broad jump and push-ups (12, 42).

5.4.2 Repetitive lifting

Tests designed to measure repetitive lifting capacity include tests of repetitive lifting maximal oxygen uptake (47, 71, 117, 149), timed maximal effort tests (14, 40, 115, 118), tests of maximum acceptable load (19, 69, 70, 85, 120, 131), timed completion of a set amount of work (146) or a set work rate to exhaustion (148). Most repetitive lifting tests are labor intensive, as the boxes that are lifted need to be lowered, either using an automated system (automated shelf or rollers) or manually.

5.4.3 Repetitive lifting maximal oxygen uptake

Tests of repetitive lifting maximal oxygen uptake are progressive in nature, either increasing the load lifted, the rate of lifting, or both, until the maximum rate of oxygen consumption has been reached (52, 71, 88, 94, 117, 149). Metabolic measurement equipment is needed to conduct the tests, and they are not commonly used to evaluate L-L&C performance. Table 7 lists the VO2peak for men and women for several modes of exercise.

Table 7: VO2peak for various testing modalities in men and women.

	Men (117)	**Women** (86)
	VO2peak (L/min)	*VO2peak (L/min)*
Treadmill	4.12 (0.53)_	2.78 (0.38)
Leg Cycle	3.63 (0.56)	NA
Upper Arm Cycle	2.57 (0.46)	NA
Repetitive Lifting	3.20 (0.42)	2.32 (0.27)

5.4.4 Maximal effort timed repetitive lifting test

A maximal-effort, timed repetitive lifting test was used to simulate the re-supply of a 155mm self-propelled howitzer (118). The final test score was the maximum number of 21 to 41 kg boxes lifted to a 132 cm high shelf in a 10 min period. Similar protocols with varying weights (20.9-41.0 kg) and varying lengths of time (5-10 min) have been used to examine the repetitive lifting capacity of men and women before and after physical training programs(40, 54, 55, 64, 116). These tests have been shown to have high test-retest reliability with a stable score obtained after two trials(54, 90, 118).

5.4.5 Maximum acceptable weight of lift (MAWL)

As mentioned earlier (Section 5.2.4.3), tests of the maximum acceptable load or lifting rate involve a subjective measure of the exercise intensity an individual is willing to work at under a defined set of conditions. Snook and colleagues have developed an extensive data set for a wide variety of L-L&C tasks with loads determined to be acceptable to various percentages of the population of US workers (19, 129-131). While these tests provide useful information for setting limits and equipment design guidelines, they can also be used to measure performance before and after a training program (120).

5.4.6 Completion of a set amount of work

The Canadian Army repetitive lifting task involves lifting 20.9 kg boxes from the floor onto a 1.3 m truck bed 48 times in 5 min (9.6 lifts/min). As with all the Canadian common task requirements, the scoring is pass/fail, and does not discriminate well between skill levels (68).

5.4.7 Timed work rate to exhaustion

The Dutch Army repetitive lifting test involves lifting loaded boxes from the floor to 145 cm at the rate of 6 lifts/min for 90-second periods. The initial box load is 12 kg. The load is increased by 4 kg during a 30 sec rest period at the end of each 90 sec lifting period. The maximum load is 56 kg. This load is administered two times if the volunteer is successful. The maximum number of lifts completed, while maintaining the lifting pace is the final score (possible range=0-117 lifts). The average man (n=137) lifted the 52 kg box five times for a total of 95 lifts. The average woman (n=59) lifted the 32 kg box two times for a total of 47 lifts (140).

5.4.8 Continuous and repetitive carrying

Carrying and repetitive carrying tests incorporate walking while holding an object. These tasks are the most commonly performed physically demanding tasks conducted by the US Navy (111), and the Armies of both the US (121) and the UK (97). Reported tests include maximal effort timed tests (12, 12, 40), continuous carrying tests (35, 106) and maximum acceptable load determinations (123). The reported loads for bi-manual carrying (one object in each hand) ranged from two-10 kg jerry cans to two-35 kg cans (total load 20 to 70 kg). Twenty kg sandbags and 34 kg boxes have been used for carrying one object with both hands. The U.S. Navy utilized a box carry with distance carried as the measure of performance. Sailors carried a 34 kg box with handles along a 51.4 m up-and-back course for two-five minute periods. The box was placed on a table, and Sailors walked the distance without a box. The final score was the distance covered during the two-five minute exercise periods (42).

The British Army developed a set of representative military tasks that included a single maximum lift, a repetitive lift and carry test and a continuous carry to exhaustion (97). The single lift task was a lift from the ground to 1.45 or 1.70 m of an ammunition box with handles. The initial load was 10 kg. Load increments were 5 kg for men and 2.5 kg for women until a load of 40 kg was reached. After 40 kg was lifted, the load increments were 4 kg for men and 2 kg for women. For the repetitive lift and carry test, 3 box loads, either 10, 22 or 44 kg, were lifted, carried 10 m, and lifted onto a platform at rates of 6, 3 or 1 shuttles per min, respectively. The load and rate standard was based on the requirements of the Soldier's assigned job. All Soldiers tested were able to complete the required lift and carry task for their assigned job. This test was later dropped from the test battery. For the continuous carry, Soldiers walk up and down a 30 m course at a rate of 1.5 m/sec while carrying a 20 kg jerry can in each hand. The test is over when the Soldier can no longer maintain the pace, or when the jerry cans are placed on the ground. The final score is the distance (m) covered (103). There are five levels of acceptable performance, with the passing standard based on the physical demands of the soldiers' job (PSSR Pamphlet).

The Dutch Army repetitive carrying task is the only progressive test. Two-15 kg cans are carried 90 meters twice (180 m total) at a speed of 5.3 km/hr (3.3 mph). The cans are then replaced with cans that are 4 kg heavier until the Soldier cannot maintain the pace, or until the maximum load of 35 kg is reached. The average male Soldier (n=135) completed the segment with the 27 kg cans and failed during the 31 kg cans. The average female Soldier completed the 19 kg load and failed during the 23 kg load. The final score is the total distance walked. Performance on this carrying task (total distance completed) was best predicted by measures of upper body aerobic capacity, strength and body size (142).

5.5 NATO FORCES PREDICTION OF MMH PERFORMANCE

5.5.1 British Army Program

One of the most comprehensive and well documented efforts to predict common military manual material handling capability was undertaken by the British Army (97-100, 102-105). They conducted a detailed job analysis of all entry-level Army occupations and identified four Representative Military Tasks (RMTs) that were common to most military occupations and critical to soldier performance (97). Three of the tasks involved L-L&C. These were a 1RM lift of an ammunition box, a continuous carry of 2-20 kg water jugs (jerry cans), and a repetitive lift and carry of an ammunition box (see Table 8). The repetitive lift and carry test was later dropped. Based on the actual array of job demands, all Army jobs were assigned to one of five levels of difficulty within each task (2). The difficulty of the task was altered using different loads and carry distances. Each employment group, or job specialty, was assigned to the appropriate difficulty level for each task. Soldiers from various specialties were then tested on the RMTs and on a comprehensive battery of

physical fitness and anthropometric measurements (98). These data were used to develop a series of models to predict the RMTs (102). The predictive models were cross-validated in a separate study using a group of initial-entry trainees (99). 1RM box lifting was best predicted by fat-free mass and muscle strength measures. The continuous carrying models used muscular endurance and anthropometric measures. The repetitive L&C models included muscular strength, muscular endurance, and anthropometric measures. The 1RM lifting models worked well, but the continuous carry and repetitive lift and carry models did not accurately predict success on the criterion tasks.

Table 8: Performance standards for representative military MMH tasks

Task Level	Single Lift of Ammunition Box (Measure: Max load)	Carry (Measure: Time to exhaustion in min)	Repetitive Lift and 10 m Carry of Ammunition Box (Measure: Time to exhaustion up to 60 min)
1	Lift 45 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 180 m in 2:00	44 kg, ground to 1.45 m, 1/min
2	Lift 40 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 150 m in 1:40	22 kg, ground to 1.45 m, 3/min
3	Lift 35 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 120 m in 1:20	10 kg, ground to 1.45 m, 6/min
4	Lift 30 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 180 m in 2:00	NA
5	Lift 25 kg to 1.45 m	Carry 2 jerry cans (20 kg each) for 180 m in 2:00	NA

5.5.2 U.S. Air Force Program

The US Air Force designed an initial entry screening test to assign recruits to jobs for which they were physically qualified(11, 75). A job analysis was conducted for all of the Air Force specialties. The physically demanding tasks were identified and quantified. A series of predictor tests were used to model performance on 13 representative lifting and lifting and carrying tasks. Incremental Lift Machine (ILM) strength to 183 cm was found to be the best predictor in 11 of the 13 tasks and the second best predictor in the other 2 tasks. The ILM test was selected for pre-assignment screening. The lifting height on the ILM is a common lifting height for loading aircraft. All job descriptions were assigned a rating for the ILM load that must be lifted for an individual to qualify. The load was based on the average demands of the job, rather than the maximum demands, because it was assumed an Airman could request help in lifting during the heaviest lifts. A report by the US General Accounting Office was critical of the accuracy of the system(1), but Dr McDaniel reports that this placement system is working well (personal communication, Dr. Joseph McDaniel, Dec 2004).

5.5.3 U.S. Army Program

The ILM weight stack machine lifting test was also used by the US Army. A three phase study was conducted (137) in which a group of new recruits was tested on entry to Basic Combat Training (BCT) (Phase 1), during the last week of BCT (Phase 2), and near the end of Advanced Individual Training (AIT) (Phase 3). The only CMT was a 1RM box lift to 132 cm. The physical fitness measures selected to predict 1RM box lift included isometric hand grip, isometric 38-cm upright pull, an ILM to 2 heights (152 cm and 183 cm), a bicycle test of predicted VO2max (Astrand-Rhyming test) or a step test of predicted VO2max, and a skinfold estimate of body composition. While the Air Force ILM test was to 183 cm, the Army used a lifting height of 152 cm. This was because the 152 cm height represented lifting a box with handles (handles 20 cm from the bottom of the box) to the height of a 2-1/2 ton truck (137). The 1RM box lift was measured at the end of BCT and a multiple regression analysis was conducted to predict the CMT from the measures of physical fitness. Fat-free mass and ILM produced multiple regression correlation coefficients (R^2) of 0.33, 0.11 and 0.47 for men, women, and combined genders, respectively. The standard error of the estimate was too large for the gender combined equation to be recommended for further use.

Figure 3. Incremental Lift Machine (starting and ending position).

Using the physical fitness data collected by Teves et al (137), and the same Phase 3 volunteers, a modelling study was conducted concurrently by Myers et al (84). The following additional criterion measures were made: 1RM box lift, a prolonged carry, pushing, and applying torque (turning a wrench). The criterion tasks and the physical fitness predictors were measured at the end of AIT. A combined score was calculated to represent performance on the four criterion tasks. The ILM was found to be the best predictor of the combined score (84). Pre-assignment ILM standards were set for Soldiers. In a two year follow on study, the US Army was unable to establish the efficacy of the program and dropped the screening test in the early 1990s (141).

5.5.4 Canadian Forces Program

The Canadian Forces have identified three L-L&C common military tasks: Land casualty evacuation, sea casualty evacuation and a sandbag carry (132). These tasks were standardized for evaluation purposes to develop tasks that could be tested on one soldier. The land evacuation involves one person carrying the front end of a litter, with wheels on the back for .75 km. The litter was loaded to 40 kg (representing ½ of an 80 kg man). The sea evacuation task was conducted in fire fighting protective clothing and consisted of three parts. An 80 kg litter was moved 12.5 m, then a 40 kg litter was pushed up and down a ship staircase and finally, the 80 kg litter was carried back to the starting position. The sandbag carry task required the movement of 20 kg sandbags a distance of 50 m as many times as possible in 10 min. The passing score for these CMTs was the 75th percentile, or the score at which 75% of the tested population would pass the test. The distribution was corrected for differences in the number of men and women. The EXPRES physical fitness test (sit-ups, push-ups, combined maximal grip strength and step test prediction of VO2max) was used to predict performance on the criterion tasks. While the EXPRES tests were significantly correlated with the CMTs, they were not strong predictors. The 5th percentile on each fitness test for the population of subjects who achieved the 75th percentile on all criterion tasks became the passing score. These standards for the EXPRES test are considered to be the minimal level of physical fitness needed to successfully perform the CMTs. The soldier readiness tests, fitness checks and training procedures are all age and gender free (68, 132-134).

The Canadian Land Forces Command Army Fitness Manual (146) lists two L-L&C CMTs. The casualty evacuation task is a fireman lift and carry of an equally sized soldier for 100m in less than 60 sec. The ammunition box lift requires the soldier to lift 20.9 kg boxes from the floor to 1.3 m, 48 times in under 5 minutes. Canadian soldiers are tested on the casualty evacuation task annually. The Army Fitness Manual provides a Fitness Check to assess an individual's fitness level and ability to perform the CMTs. The standards include four levels of performance on measures of aerobic capacity (2400 m run, 5 km run), strength (bench press, squat, sit-ups) and power and speed (long jump, two jump and 40m sprint). Detailed training instructions are provided to assist the soldier in achieving the standard.

5.5.5 Royal Netherlands Army Program

The Royal Netherlands Army designed two L-L&C CMT tests: a repetitive lift (140) and a carry(142). Each test is progressive in nature with the goal of obtaining a maximum measure of performance. The Repetitive Lifting Task involved lifting a box from the floor to 145 cm one time/10 sec for 9 repetitions. The initial weight in the box was 12 kg and the weight was increased in 4 kg increments. Thirty seconds of rest were given between each load increase. This sequence was repeated until the soldier could not keep up with the pace. The performance measure was the number of repetitions. The Carry Task involved a progressive, interrupted jerry can carry of 90 m at a pace of 5.4 km/h. The initial load was 15 kg was increased by 4 kg each trip with 1 min rest between trips. The task ended when the soldier could not maintain the pace and the performance measure was the distance covered. The tests were performed by a group of Soldiers who also performed a series of laboratory and field measures of physical capacity. The more traditional physical capacity tests were used to predict performance on the occupational tasks, and these traditional tests were used to place Royal Netherlands Army recruits into jobs compatible with their physical ability.

5.6 TRAINING FOR MANUAL MATERIALS HANDLING

Increasing physical fitness in Soldiers is an important part of protecting them from injury (55), while improving their occupational performance. Ninety percent of physically limiting tasks of Army MOSs include lifting or lifting and carrying (114, 122), and all manual materials handling tasks rely on muscular strength and endurance. By increasing muscular strength and endurance of soldiers, they can perform the same MMH

tasks at a lower percentage of their capacity, reducing fatigue and reducing the risk of injury (54, 55). Cardiorespiratory endurance training can also be beneficial for materials handling tasks that are done for longer periods, such as manually lifting boxes for several minutes or hours (63). The benefits of proper physical training for Soldiers also include improved health, longevity, and lower medical costs (13, 16, 83, 89), benefiting both the soldier and improving military readiness.

Physical training is defined as muscular activity designed to enhance the physical capacity of the individual by improving one or more of the components of physical fitness (63). The three most important fitness components include muscular strength, muscular endurance and cardiorespiratory endurance (aerobic capacity). Muscular strength is the ability of a muscle group to exert maximal force in a single voluntary contraction. Muscular endurance is the ability of a muscle group to perform short-term, high-power physical activity. Cardiorespiratory endurance depends on the functioning of the circulatory and respiratory systems.

5.6.1 Training types

Performance gains in manual materials handling depend on three physical improvements through training: psychomotor learning, improved muscle strength, and cardiovascular changes (63). Psychomotor learning will result from improved neural coordination. Improved strength results from increased muscle activation and hypertrophy. Cardiovascular changes are the result of adaptations of the circulatory and respiratory systems through endurance training.

Training to improve manual materials handling performance can be grouped by the type of training, either task-specific or general (traditional). Task specific training includes training by performing movements similar to the actual task, but organized as progressive resistance training. General or traditional training includes doing aerobic and weight training for general fitness. Where task-specific training utilizes equipment similar to military situations, such as ammunition boxes and truck beds, traditional training would use weight training equipment found in most gymnasiums. In order to be effective, both training protocols must include progressive resistance training (PRT). PRT is accepted as the most effective way to improve performance in sports (118). Progression is achieved through the concept of progressive overload which involves small, systematic increases in the frequency, intensity and/or duration of the exercise as fitness improves (74).

5.6.1.1 Task specific training

Progression in task-specific training is an important way to increase occupational performance. Progression can be accomplished in manual materials handling by increasing the load (weight lifted), the rate (times per minute) of lift, duration (time per training session), or the frequency (training days per week). Increasing the rate or duration can increase aerobic gains, increasing the load will increase strength, and increasing the total number of repetitions can improve muscular endurance. Task-specific training has the advantage of a shorter training period for improving specific operational tasks because specific physiological adaptations, especially neural adaptations are rapidly acquired. The downside is that the gains are largely restricted to the muscle groups and movements trained, and there may be limited improvements for other types of tasks. Task-specific training is usually difficult for large groups of soldiers to perform because it requires a specialized training environment and equipment. The need for specialized equipment and non-traditional exercises could result in a more dangerous or less controlled training environment compared to more traditional training. Task-specific training is best used for soldiers who have a repetitive and predictable task where loads and movements can be defined. This type of training is also useful for any materials handling tasks that require a higher skill level because strength and skills can be achieved through specificity of training.

Psychophysical training is a form of task-specific training, where the individual sets the exercise intensity and makes adjustments based on their perception of discomfort. It has been shown to improve job performance of inexperienced lifters (1 hr repetitive lifting capacity test), but may result in limited improvements in general physical fitness (120). Psychophysical training may result in increased muscular endurance, which is important for highly repetitive lifting tasks (120).

A summary of the improvements that have been found through task specific training is summarized in Table . The improvements noted by Genaidy et al (30-35) in endurance time appear to be much larger than for any other form of training. It is likely that some portion of the increases in endurance time were due to learning effects, as the tasks were extremely complex. Asfour et al (8) reported large increases in a 1RM box lifting task to three different heights, and noted that most of the increases occurred after the first two weeks of training. These authors concluded that a two week training program was sufficient to improve box lifting strength. It is likely, however, that most of these increases were due to psychomotor learning, especially improved technique and familiarity with the task.

Table 9: Summary of task-specific training and improvements in materials handling

Author	Year	N	Sex[a]	Population	Weeks	Testing	Description	% Improvement
Asfour et al.	1984	10	M	Students	6	1RM box lift	0-76 cm	41%
							76-127 cm	99%
							0-127cm	55%
						Vo2max	Cycle Ergometer	24%
Sharp and Legg	1988	8	M	Soldiers	4	Box Lift	1RM 0-132cm	7%
							Psychophysical Mass	26%
							VO_2max (direct)	6%
Genaidy et al.	1989	11	M	Civilians	2.5	Lift and Carry	Endurance time to fatigue	102%
Genaidy et al.	1990b	15	M	Civilians	6	Lift, carry, push and pull Group A: 6 RM[d] Load Group B: 10 RM Load	1RM	a. & b. 32%
							20 kg, 8 lifts/min endurance	Time/Heart Rate A. 57% / 10% B. 172% / 7%
Genaidy et al.	1990a	27	M	Students	4	Lift and Lower	Endurance time to fatigue	Sym[b]: 248%, Asym[c]: 46%
							Frequency of handling	Sym: 44%, Asym: 34%
Genaidy et al.	1991	20	M	Students	6	Lift, carry, push/ pull: Group A: 15 kg both hands Group B: 8 kg separate hands	Endurance time to fatigue	A. 557%, B. 1350%
							Heart rate	A. 18%, B. 9%
Genaidy et al.	1994	23/5	M/W	Industrial Workers	6	Lift, carry, push and pull	1RM	58-84%
							Endurance time to fatigue	117-127%
							Total Cycles	107-183%

[a]M=men,W=women, [b] Sym=symmetrical lift, [c] Asym=asymmetrical lift, [d] RM=Repetitions Maximum i.e. only 6 or 10 repetitions could be completed with that load

5.6.1.2 General training

General training takes a longer training period to produce improvements in materials handling, because the increase in performance is attributed to neural adaptations, muscle hypertrophy and some improvement in cardiorespiratory endurance. General training is not limited to the specific tasks trained, and therefore has the potential to improve performance on a wider variety of tasks than task-specific training. General training is usually safer than task-specific training and most military training facilities have traditional training equipment, designed with safety in mind. General training can improve whole body fitness and should be used in situations where occupational tasks vary. The increase in overall fitness associated with more traditional training may also be effective in preventing muscular imbalances and overuse injuries. Generalized training is better for military, police, and fire fighting where there are varied occupational tasks requiring heavy physical labour (63). Twelve weeks of general training can significantly improve performance, however task performance improvements have been seen in as little as 4 (116) to 8 weeks (24, 39).

When a "carefully structured progressive resistance training element" was added to British Army Basic Training, the increase in materials handling was much greater (12.4%) than the original basic training regimen (1 to 4%). Most of this training was general, but there were some specific skills training sessions as well (147). For women, general training can improve materials handling performance, especially when the training includes exercises are designed to increase upper body strength (87). Table show a comparison of several different training programs. Maximal lifting capacity was not affected by aerobic endurance training, but improved with every type of general PRT. Additional studies of general physical training and improvements in manual material handling, including studies of new recruits can be seen in Table 12.

Table 10: Comparison of upper vs total body progressive resistance training programs in women

Study	N	Weeks	Sessions	Program	Maximal Lift	Repetitive Lift
Nindl (1998)	46	12	36	Total Body PRT	15%	24%
				Upper Body PRT	14%	22%
Kraemer et al. (2001)	93	24	72	Total body strength/power PRT	27%	33%
				Total body strength/hypertrophy PRT	24%	33%
				Upper body strength/power PRT	12%	30%
				Upper body strength/hypertrophy PRT	19%	41%
				Plyometric/Partner PRT	17%	29%
				Aerobic Training	0%	29%

Table 11: General training programs and percent improvement in materials handling tasks

Author	Year	N	Sex	Population	Weeks	Testing	Description	% Improvement
Sharp et al.	1993	18	M	Soldiers	12	1RM box Lift	1RM, floor to chest	23%
						Repetitive Lift	10 Min, 41 kg, floor to chest	18%
						VO2max	Direct	2%
Knapik and Gerber	1996, 1997	13	F	Soldiers	12	1RM box Lift	Floor to knuckle	19%
							Floor to chest	16%
						Repetitive Lift	15kg, floor to chest	17%
						Maximal Run	3.2 km	9%*
Harman et al.	1996	41	F	Civilians	14	1RM box lift	Floor - 76cm	19%
							Floor - 132 cm	23%
							76 - 132 cm	32%
						Repetitive Lift	18 kg, floor - 132cm	28%
						Lift and Carry	18 kg, 8 m, lift 132 cm	11%
						VO_2max	Direct	12%

* In addition to PRT, program included 2 days/wk of running

Table 11 (cont'd): General training programs and percent improvement in materials handling tasks

Author	Year	N	Sex	Population	Weeks	Testing	Description	% Improvement
Williams et al.	2002	43/9	M/F	Soldiers	10	Maximal Box Lift	145 cm	12%
							170 cm	8%
						Repetitive lift and carry	10 kg, 10m, 145 cm	15%
							22 kg, 10 m, 145 cm	19%
Williams et al.	1999	47/10	M/F	Soldiers	10	Maximal Box Lift	145 cm	2%
							170 cm	4%
						Repetitive lift and carry	10 kg, 10m, 145 cm	7%
							22 kg, 10 m, 145 cm	30%
Brock and Legg	1997	73	F	Soldiers	6	Incremental Dynamic Lift (USAF)	Increasing resistance to max 152 cm	10%

5.6.2 Applications

There is ample evidence that PRT can improve performance in manual materials handling (7, 39, 40, 56, 63, 87, 120, 147). Task specific training is best for jobs where there little variability in the day to day work, whereas general training is better for jobs where the materials handling tasks vary from day to day (63). An ideal training regimen for soldiers would include both traditional and task specific training. Most soldiering jobs require the basic fitness associated with general training because their tasks vary by situation, but the nature of their individual jobs may also require skills and specific fitness that can only be learned through task-specific training. This combination of training programs may be effective in reducing injuries and increasing the effectiveness of soldiers who are new to the job. One example of a training program already in place is the US Army Physical Fitness School's Physical Readiness Training (60, 61, 110). This training program proscribes the exact exercise to be used, based on a task analysis of common soldiering tasks. The Physical Readiness Training Program includes interval running to improve aerobic fitness and limits the distance run to reduce overuse injuries (53, 60). British Army Basic Training produced greater improvements in materials handling than the original basic training program by adding progressive resistance training and skill specific training to the syllabus (147).

5.7 CONCLUSIONS/RECOMMENDATIONS

5.7.1 Military lifting requirements

1. L-L&C tasks are the most common physically demanding tasks performed by the Armed Forces of many of the various NATO nations.

2. L-L&C tasks (and MMH tasks in general) appear to contribute to overexertion injuries, particularly low back pain, and disability in the military and the civilian sector.

3. Low back pain and injury complaints account for the 2nd largest number of outpatient medical visits for US Army Servicemembers.

5.7.2 Recommended L-L&C Limits

1. There are published safe load recommendations for military and civilian populations.

2. When considering the safety of an object to be L-L&C, the limits should be adjusted downward if the load is not optimally configured, or if the conditions are outside the range of those described in the recommendation.

3. Loads L-L&C by servicemembers often exceed the recommended safe limits and vary from country to country.

5.7.3 Team lifting

1. Team work can be used to effectively decrease the load handled on a per-person basis, and some MMH tasks are specified to be multi-person tasks.

2. The one-repetition maximum (1RM) for dynamic two-person team lifting is 10-20% lower than the sum of individual 1RM lifts, but little further decrease is found with the addition of one or two more people. If a recommended load for an individual performing a task has been determined, the % sums from Table 1 can be used to estimate the load for two to four persons lifting as a team. It is essential that there is adequate team coordination, space, handholds, and an equal distribution of the load when performing infrequent heavy team lifting tasks.

3. Repetitive team lifting and carrying maximum acceptable weight of lift (MAWL) tends to be equal to or greater than the sum of the individual MAWL for the same task. Therefore, doubling the individual MAWL provides a reasonable estimate of the load two-person teams will find acceptable for a repetitive MMH task if the individual MAWL is known. This is most appropriate for tasks that are symmetrical. It is essential that there is adequate team coordination, space, handholds, and an equal distribution of the load when performing infrequent heavy team lifting tasks.

4. Where possible, individuals should be roughly matched for strength. When a large strength discrepancy exits between two persons performing a repetitive team lifting task, the weaker individual works at a higher relative intensity, predisposing that person to early fatigue and possible injury. For 1RM lifting, the lower strength individual limits the maximum load that can be lifted.

5. A number of prediction equations have been published to estimate team lifting strength based on the characteristics of the individuals lifting.

6. Litter carriage is an important team L&C task. The time to exhaustion for carrying long distances can be greatly extended with the use of shoulder straps or specialized harnesses that have been described in the literature.

5.7.4 Physiological Requirements

1. The energy cost of a repetitive L-L&C task is influenced by technique, object characteristics and task variables. A number of published equations to estimate energy expenditure of L-L&C tasks are included in this report (Table 4).

2. It is generally recommended that the exercise intensity of a L-L&C task not exceed 28-35% if it must be maintained for an 8 hour day. The intensity can be increased with decreasing durations of exercise.

5.7.5 Evaluation of L-L&C Task Performance

1. L-L&C task performance of an individual or team can be evaluated using one time maximum test, maximum performance of a repetitive task, with time, work or exercise intensity as the end point, maximum acceptable weight of lift determinations, or tests to exhaustion.

2. A number of NATO countries have implemented some form of physical performance testing to directly or indirectly measure L-L&C performance. Typically this testing is in addition to testing for physical fitness.

5.7.6 Training

1. Progressive resistance training will improve manual materials handling ability and is likely to reduce injury in soldiers because so many soldiering tasks require manual materials handling. For lower strength soldiers it is particularly important to include upper body progressive resistance training exercises.

2. Task-specific training should be designed for jobs that are the same from day-to-day or require specialized movement skills. The gains from task-specific training, will be realized more quickly than with general training, presumably because of increased neural coordination.

3. General training can improve whole body fitness and should be used when occupational tasks change from day-to-day or where increased physical demands can be sudden or unexpected. General training is not limited to the specific tasks trained, and therefore has the potential to improve performance on a wider variety of tasks than task-specific training.

CHAPTER 5 - REFERENCES

1. *Physically demanding jobs: Services have little data on ability of personnel to perform* (Technical Report) GAO/NSIAD-96-169. Washington,D.C.: U.S. Government Printing Office, 1996.

2. Fit to Fight (Pamphlet two), Test protocols and administrative instructions for physical selection standards (recruits): Representative Military Tasks. 2002. Upavon, Wiltshire, UK, Ministry of Defence.

3. *Human factors for designers of equipment Part 3: Body strength and stamina* (Technical Report) Defence Standard 00-25 (Part 3)/Issue 2. Glasgow, UK: Ministry of Defence, 1997.

4. *Military Standard Human Engineering Design Criteria for Military Systems, Equipment and Facilities*. Philadelphia, PA: Naval Publications and Forms Center, 1989.

5. **Asfour, S., Ayoub, M., Genaidy, A., and Khalil, T.** A data base of physiological responses to manual lifting. In: Trends in Ergonomics/Human Factors III, Louisville, KY: 1986, 801-809.

6. **Asfour S., A. Genaidy, T. Khalil and S. Muthuswamy**. Physiological responses to static, dynamic and combined work. *Am Ind Hyg Assoc J* 47(12): 798-802, 1986.

7. **Asfour, S. A., Dutta, S. P., and Tabourn, S. M.** The effects of training on static strength and carrying capacity of college males. In: Trends in Ergonomics/Human Factors I, Cincinnati, OH: 1984, 161-166.

8. **Asfour S.S., M.M. Ayoub and A. Mital**. Effects of an endurance and strength training programme on lifting capability of males. *Ergonom* 27(4): 435-442, 1984.

9. **Asfour S.S., M. Tritar and A.M. Genaidy**. Endurance time and physiological responses to prolonged arm lifting. *Ergonom* 34(3): 335-342, 1991.

10. **Ayoub M., A. Mital, S. Asfour and N. Bethea**. Review, evaluation, and comparison of models for predicting lifting capacity. *Hum Factors* 22(3): 257-269, 1980.

11. **Ayoub M.M., B.C. Jiang, J.L. Smith, J.L. Selan and J.W. McDaniel**. Establishing a physical criterion for assigning personnel to U.S. Air Force jobs. *Am Ind Hyg Assoc J* 48: 464-470, 1987.

12. **Beckett M.B. and J.A. Hodgdon**. *Lifting and carrying capacities relative to physical fitness measures* (Technical Report) 87-26. San Diego, CA: Naval Health Research Center, 1987.

13. **Bertera R.L.** The effects of workplace health promotion on absenteeism and employment costs in a large industrial population. *Am J Public Health* 80: 1101-1105, 1990.

14. **Bilzon J.L., E.G. Scarpello, E. Bilzon and A.J. Allsopp**. Generic task-related occupational requirements for Royal Naval personnel. *Occup Med (Lond)* 52: 503-510, 2002.

15. **Bilzon J.L., E.G. Scarpello, C.V. Smith, N.A. Ravenhill and M.P. Rayson**. Characterization of the metabolic demands of simulated shipboard Royal Navy fire-fighting tasks. *Ergonom* 44: 766-780, 2001.

16. **Blair S.N., H.W. Kohl, III, C.E. Barlow, R.S. Paffenbarger, Jr., L.W. Gibbons and C.A. Macera**. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. *JAMA* 273: 1093-1098, 1995.

17. **Chaffin D.B.** Human strength capability and low-back pain. *J Occup Med* 16: 248-254, 1974.

18. **Chaffin D.B.** Manual materials handling and the biomechanical basis for prevention of low-back pain in industry-an overview. *Am Ind Hyg Assoc J* 48: 989-996, 1987.

19. **Ciriello V.M., S.H. Snook, A.C. Blick and P.L. Wilkinson**. The effects of task duration on psychophysically-determined maximum acceptable weights and forces. *Ergonom* 33(2): 187-200, 1990.

20. **Department of the Army H.** *Enlisted Career Management Fields and Military Occupational Specialty* (Technical Report) 6. Washington, DC: U.S. Government Printing Office, 1995.

21. **Doolittle, T. L., Spurlin, O., Kaiyala, K., and Sovern, D.** Physical demands of lineworkers. Santa Monica, CA: Human Factors Society, 1988, 632-636.

22. **Feuerstein M., S.M. Berkowitz and C.A. Peck**. Musculoskeletal-Related Disability in US Army Personnel: Prevalence, Gender, and Military Occupational Specialties. *J Occup Environ Med* 39: 68-78, 1997.

23. **Fox R.R.** *A psychophysical study of bi-manual lifting*. Texas Technical University, Lubbock, TX: M.S. Industrial Ergonomics, 1982.

24. **Frykman P., E. Harman, D. Gutekunst and B. Nindl**. Effects of U.S. Army standardized physical training and a weight training program on body composition. *Med Sci Sports Exerc* 38: S272, 2006.

25. **Gardner L.I., D.P. Landsittel and N.A. Nelson**. Risk factors for back injury in 31,076 retail merchandise store workers. *Am J Epidemiol* 150: 825-833, 1999.

26. **Garg A., D. Chaffin and G. Herrin**. Prediction of metabolic rates for manual materials handling jobs. *Am Ind Hyg Assoc J* 39: 661-674, 1978.

27. **Garg, A. and Herrin, G.** Stoop or Squat: A Biomechanical and Metabolic Evaluation. 1979, 293-302.

28. **Garg, A., Rodgers, S. H., and Yates, J. W.** The physiological basis for manual lifting. Kumar, S. London: Taylor & Francis, 1992, 867-874.

29. **Garg A. and U. Saxena**. Physiological Stresses in Warehouse Operatios with Special Reference to Lifting Technique and Gender: a case study. *Am Ind Hyg Assoc J* 46(2): 53-59, 1985.

30. **Genaidy A., N. Davis, E. Delgado, S. Garcia and E. Al-Herzalla**. Effects of a job-simulated exercise programme on employees performing manual handling operations. *Ergonom* 37: 95-106, 1994.

31. **Genaidy A.M.** A training programme to improve human physical capability for manual handling jobs. *Ergonom* 34(1): 1-11, 1991.

32. **Genaidy A.M., K.M. Bafna and R. Sarmidy**. A muscular endurance training program for symmetrical and asymmetrical manual lifting tasks. *J Occup Med* 32(3): 226-233, 1990.

33. **Genaidy A.M., T. Gupta and A. Alshedi**. Improving human capabilities for combined manual handling tasks through a short and intensive physical training program. *Am Ind Hyg Assoc J* 51: 610-614, 1990.

34. **Genaidy A.M., W. Karwowski, L. Guo, J. Hidalgo and G. Garbutt**. Physical training: A tool for increasing work tolerance limits of employees engaged in manual handling tasks. *Ergonom* 35(9): 1081-1102, 1992.

35. **Genaidy A.M., A. Mital and K.M. Bafna**. An endurance training programme for frequent manual carrying tasks. *Ergonom* 32(2): 149-155, 1989.

36. **Gordon C., T. Churchill, C. Clauser, B. Bradtmiller, J. McConville, I. Tebbetts and R. Walker**. *1988 Anthropometric survey of U.S. Army personnel: Methods and summary statistics* (Technical Report). Natick, MA: U.S. Army Natick Research, Development and Engineering Center, 1988.

37. **Griffin A.B., J.D. Troup and D.C. Lloyd**. Tests of lifting and handling capacity. Their repeatability and relationship to back symptoms. *Ergonom* 27: 305-320, 1984.

38. **Hagen K.B., K. Harms-Ringdahl and J. Hallen**. Influence of lifting technique on perceptual and cardiovascular responses to submaximal repetitive lifting. *Eur J Appl Physiol* 68: 477-483, 1994.

39. **Harman E., P. Frykman, D. Gutekunst, B. Nindl and J. Alemany**. U.S. Army standardized physical training vs. a weightlifiting-based program: Effects on soldier physical performance. *Med Sci Sports Exerc* 38: S272, 2006.

40. **Harman E., P. Frykman, C. Palmer, E. Lammi, K. Reynolds and V. Backus**. *Effects of a specifically designed physical conditioning program on the load carriage and lifting performance of female soldiers* (Technical Report) T98-1. Natick, MA: 1997.

41. **Hidalgo J., A. Genaidy, W. Karwowski, D. Christensen, R. Huston and J. Stambough**. A comprehensive lifting model: beyond the NIOSH lifting equation. *Ergonom* 40: 916-927, 1997.

42. **Hodgdon J.A. and M.B. Beckett**. *Body estimation and physical performance: estimation of lifting and carrying from fat-free mass* (Technical Report) 98-37. San Diego,CA: Naval Health Research Center, 1998.

43. **Intaranont, K., Ayoub, M., Bobo, W., and Smith, J.** Physical lifting capacity: The anaerobic threshold approach. Louisville, KY, 1986, 835-846.

44. **Jette M., A. Kimick and K. Sidney**. Evaluating the occupational physical fitness of Canadian forces infantry personnel. *Mil Med* 154: 318-322, 1989.

45. **Johnson, S. L. and Lewis, D. M.** A psychophysical study of two-person manual materials handling tasks. In: Proceedings of the Human Factors Society 33rd Annual Meeting, 1989, 651-653.

46. **Jorgensen K.** Permissible loads based on energy expenditure measurements. *Ergonom* 28(1): 365-369, 1985.

47. **Jorgensen K. and E. Poulsen**. Physiological problems in repetitive lifting with special reference to tolerance limits to the maximum lifting frequency. *Ergonom* 17(1): 31-39, 1974.

48. **Karwowski, W.** Maximum load lifting capacity of males and females in teamwork. In: Proceedings of the Human Factors Society 32nd Annual Meeting, 1988, 680-682.

49. **Karwowski W. and A. Mital**. Isometric and isokinetic testing of lifting strength of males in teamwork. *Ergonom* 29(7): 869-878, 1986.

50. **Karwowski W. and N. Pongpatanasuegsa**. Testing of isometric and isokinetic lifting strengths of untrained females in teamwork. *Ergonom* 31(3): 291-301, 1988.

51. **Karwowski W. and J.W. Yates**. Reliability of the psychophysical approach to manual lifting of liquids by females. *Ergonom* 29 (2): 237-248, 1986.

52. **Khalil T., A. Genaidy, S. Asfour and T. Vinciguerra**. Physiological limits in lifting. *Am Ind Hyg Assoc J* 46(4): 220-224, 1985.

53. **Knapik J., S. Darakjy, S. Scott, K.G. Hauret, S. Canada, R. Marin, W. Rieger and B.H. Jones**. Evaluation of a standardized physical training program for basic combat training. *J Strength Cond Res* 19: 246-253, 2005.

54. **Knapik J.J.** The influence of physical fitness training on the manual material handling capability of women. *Appl Ergon* 28: 339-345, 1997.

55. **Knapik J.J., S. Darakjy, K.G. Hauret, S. Canada, S. Scott, W. Rieger, R. Marin and B.H. Jones**. Increasing the physical fitness of low-fit recruits before basic combat training: an evaluation of fitness, injuries, and training outcomes. *Mil Med* 171: 45-54, 2006.

56. **Knapik J.J. and J. Gerber**. *The influence of physical fitness training on the manual material-handling capability and road-marching performance of female soldiers* (Technical Report) ARL-TR-1064. Aberdeen Proving Ground, MD: U.S. Army Research Laboratory, 1996.

57. **Knapik J.J., W. Harper and H.P. Crowell**. Physiological factors in stretcher carriage performance. *Eur J Appl Physiol Occup Physiol* 79: 409-413, 1999.

58. **Knapik J.J., W. Harper, H.P. Crowell, K. Leiter and B. Mull**. Standard and alternative methods of stretcher carriage: performance, human factors, and cardiorespiratory responses. *Ergonom* 43: 639-652, 2000.

59. **Knapik J.J., W.H. Harper, H.P. Crowell, K.L. Leiter and B.T. Mull**. *Standard and alternate methods of stretcher carriage: Performance, human factors, and cardiosrespiratory responses* (Technical Report) ARL-TR-1596. Aberdeen Proving Ground,MD: Army Research Laboratory, 1998.

60. **Knapik J.J., K. Hauret, J.M. Bednarek, S. Arnold, M. Canham-Chervak, A. Mansfield, E. Hoedebecke, J. Mancuso, T.L. Barker, D. Duplessis, H. Heckel and J. Peterson**. *The victory fitness program: Influence of the US Army's emerging physical readiness training doctrine on fitness and injuries in basic combat training* (Technical Report) 12-MA-5762-01. Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine, 2001.

61. **Knapik J.J., K.G. Hauret, S. Arnold, M. Canham-Chervak, A.J. Mansfield, E.L. Hoedebecke and D. McMillian**. Injury and fitness outcomes during implementation of physical readiness training. *Int J Sports Med* 24: 372-381, 2003.

62. **Knapik J.J., B.H. Jones, M.A. Sharp, S. Darakjy, S. Jones, K.G. Hauret and G. Piskator**. *Pre-enlistment physical fitness testing: Background and recommendations* (Technical Report). Aberdeen Proving Ground,MD: USACHPPM, 2004.

63. **Knapik J.J. and M.A. Sharp**. Task-specific and generalized physical training for improving manual-material handling capability. *Int J Indust Ergon* 22: 149-160, 1998.

64. **Kraemer W.J., S.A. Mazzetti, B.C. Nindl, L.A. Gotshalk, J.S. Volek, J.A. Bush, J.O. Marx, K. Dohi, A.L. Gomez, M. Miles, S.J. Fleck, R.U. Newton and K. Hakkinen**. Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc* 33: 1011-1025, 2001.

65. **Kraus J.F., K.B. Schaffer, D.L. McArthur and C. Peek-Asa**. Epidemiology of acute low back injury in employees of a large home improvement retail company. *Am J Epidemiol* 146: 637-645, 1997.

66. **Kumar S.** The physiological cost of three different methods of lifting in the sagittal and lateral planes. *Ergonom* 27(4): 425-433, 1984.

67. **Lavender S.A., K.M. Conrad, P.A. Reichelt, F.T. Meyer and P.W. Johnson**. Postural analysis of paramedics simulating frequently performed strenuous work tasks. *Appl Ergon* 31: 45-57, 2000.

68. **Lee S.W., P. Chahal, G. Wheeler and M. Singh**. *Physical Fitness and Work Performance Standards: A Canadian Forces Approach*. Ottawa,Canada: 1995.

69. **Legg S. and W. Myles**. Maximum acceptable repetitive workloads for a 8-hour work-day using psychophysical and subjective rating methods. *Ergonom* 24(12): 907-916, 1981.

70. **Legg S. and C. Pateman**. A physiological study of the repetitive lifting capacity of healthy young males. *Ergonom* 27(3): 259-272, 1984.

71. **Lind A. and J. Petrofsky**. Comparison of metabolic and ventilatory responses of men to various lifting tasks and bicycle ergometry. *J Appl Physiol* 45(1): 60-63, 1978.

72. **Lind A. and J. Petrofsky**. Metabolic, cardiovascular, and respiratory factors in the development of fatigue in lifting tasks. *J Appl Physiol* 45(1): 64-68, 1978.

73. **Marras, W. S., Davis, K. G., Kirking, B. C., and Bertsche, P. K.** Low back disorder risk and spinal loading during patient transfer. Santa Monica, CA: Human Factors and Ergonomics Society, 1998, 901-905.

74. **McArdle W.D., F.I. Katch and V.L. Katch**. *Exercise Physiology: Energy, Nutrition and Human Performance*. Media, PA: Williams & Wilkins, 1996.

75. **McDaniel J.W., R.J. Skandis and S.W. Madole**. *Weight lift capabilities of Air Force basic trainees* (Technical Report) 83-001. Wright-Patterson Air Force Base, OH: US Air Force Aerospace Medical Research Laboratory, 1983.

76. **Miller J., D. Farlow and M. Seltzer**. Physiological analysis of repetitive lifting. *Hum Factors* 984-988, 1977.

77. **Mital A., A. Pennathur and A. Kansal**. Nonfatal occupational injuries in the United States Part I - overall trends and data summaries. *Int J Indust Ergon* 25: 109-129, 1999.

78. **Mital A., A. Pennathur and A. Kansal**. Nonfatal occupational injuries in the United States Part II - back injuries. *Int J Indust Ergon* 25: 131-150, 1999.

79. **Mital A.** Models for predicting maximum acceptable weight of lift and heart rate and oxygen uptake at that weight. *Journal of Occupational Accidents* 75-82, 1985.

80. **Mital A. and M. Ayoub**. Effect of task variables and their interactions in lifting and lowering loads. *Am Ind Hyg Assoc J* 42: 134-142, 1981.

81. **Mital A. and W. Karwowski**. Prediction of isometric and isokinetic strengths of males in teamwork: Further applications of GMDH. *Computers and Industrial Engineering* 16: 145-159, 1989.

82. **Mital A., A.S. Nicholson and M.M. Ayoub**. *A guide to manual materials handling*. Washington, DC: Taylor & Francis, 1993.

83. **Musich S., D. Napier and D.W. Edington**. The association of health risks with workers' compensation costs. *J Occup Environ Med* 43: 534-541, 2001.

84. **Myers D.C., D.L. Gebhardt, C.E. Crump and E.A. Fleishman**. *Validation of the military entrance physical strength capacity test* (Technical Report) 610. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, 1984.

85. **Nicholson L. and S. Legg**. A psychophysical study of the effects of load and frequency upon selection of workload in repetitive lifting. *Ergonom* 29(7): 903-911, 1986.

86. **Nindl B., M.A. Sharp, R.P. Mello, V.J. Rice, M.M. Murphy and J.F. Patton**. Gender comparison of peak oxygen uptake: Repetitive box lifting vs treadmill running. *Eur J Appl Physiol* 77: 112-117, 1998.

87. **Nindl, B. C., Kraemer, W. J., Gotshalk, L. A., Meth, S., Etzweiler, S. W., Tokeshi, S. A., Sebastianelli, W. J., Putukian, M., Newton, R. U., Hakkinen, K., and Fleck, S. J.** The effects of resistance training on augmenting women's performance during a high-intensity military relevant manual materials handling task. In: Advances in Occupational Ergonomics and Safety, Kumar, S. IOS Press, 1998, 723-726.

88. **Nindl B.C., M.A. Sharp, R.P. Mello, V.J. Rice and J.F. Patton**. Gender comparison of peak oxygen uptake: Repetitive lifting vs. treadmill running. *Med Sci Sports Exerc* 27: 910, 1995.

89. **Paffenbarger R.S., Jr., R.T. Hyde, A.L. Wing and C.C. Hsieh**. Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med* 314: 605-613, 1986.

90. **Pandorf C.E., B.C. Nindl, S.J. Montain, J.W. Castellani, P.N. Frykman, C.D. Leone and E.A. Harman**. Reliability assessment of two militarily relevant occupational physical performance tests. *Can J Appl Physiol* 28: 27-37, 2003.

91. **Patton J., J. Vogel, A. Damokosh and R. Mello**. Effects of continuous military operations on physical fitness capacity and physical performance. *Work & Stress* 3(1): 69-77, 1989.

92. **Patton J.F., M. Murphy, T. Bidwell, R. Mello and M. Harp**. *Metabolic cost of military physical tasks in MOPP 0 and MOPP 4* (Technical Report) T95-9. Natick, MA: USARIEM, 1995.

93. **Petrofsky J.S. and A.R. Lind**. Metabolic, cardiovascular, and respiratory factors in the development of fatigue in lifting tasks. *J Appl Physiol* 45: 64-68, 1978.

94. **Petrofsky J.S. and A.R. Lind**. Comparison of metabolic and ventilatory responses of men to various lifting tasks and bicycle ergometry. *J Appl Physiol* 45: 60-63, 1978.

95. **Pinder A.D.J., M.G. Boocock, S.C. Monnington and N.H. Taylor**. *Team handling: A psychophysical and biomechanical study of two person handling* (Technical Report) EWP/97/35. Sheffield, UK: Health and Safety Laboratory, 1998.

96. **Randle I., S. Legg and D. Stubbs**. Task-based prediction models for intermittant load carriage. *Proc Ergonomics Soc Ann Conf 1989* 1989.

97. **Rayson, M.** The development of physical selection procedures. Phase 1: Job analysis. In: Contemporary Ergonomics, London: Taylor & Francis, 1998, 393-397.

98. **Rayson M., D. Holliman and A. Belyavin**. Development of physical selection procedures for the British Army. Phase 2: relationship between physical performance tests and criterion tasks. *Ergonom* 43: 73-105, 2000.

99. **Rayson M., D.E. Holliman, R.V. Nevola and C.L. Birch**. *Physcial selection standards for the British Army: Phase 5 validation* (Technical Report) PLSD/CHS5/CR96/021. Farnborough,UK: Center for Human Sciences, 1996.

100. **Rayson, M., Pynn, H., Rothwell, A., and Nevill, A.** The development of physical selection procedures for the British Army. Phase 3: Validation. In: Contemporary Ergonomics 2000, London: Taylor & Francis, 2000, 140-144.

101. **Rayson M.P., D.G. Bell, D.E. Holliman, M. Llewellyn, R.V. Nevola and R.L. Bell**. *Physical selection standards for the British Army phases 1 and 2* (Technical Report) DRA/CHS/HS2/2007. Farnsborough,GB: Army Personnel Research Establishment, 1994.

102. **Rayson M.P. and D.E. Holliman**. *Physical selection standards for the British Army: Phase 4 Predictors of task performance in trained soldiers* (Technical Report) DRA/CHS/PHYS/CR95/017. Farnborough,UK: Defense Research Agency, 1995.

103. **Rayson M.P., D.E. Holliman and D.G. Bell**. *Physical selection standards for the British Army: Phase 3 Development of physical selection tests and pilot study* (Technical Report) DRA/CHS/WP94006. Farnborough,UK: Defense Research Agency, 1994.

104. **Rayson M.P., D.E. Holliman, R.V. Nevola and C.L. Birch**. *Physical selection standards for the British Army: Phase 5 Validation* (Technical Report) PLSD/CHS5/CR96/021. Farnborough, UK: Defence Evaluation and Research Agency, 1996.

105. **Rayson M.P., D.M. Wilkinson and S. Blacker**. *The physical demands of CMS(R):An ergonomic assessment* (Technical Report). Surrey, UK: Optimal Performance Limited, 2002.

106. **Rice V., M. Sharp and W. Tharion**. The effect of gender, team size, and a shoulder harness on soldier performance, Part I: A simulated carry from a remote site. *Int J Indust Ergon* 18: 27-40, 1996.

107. **Rice V., M. Sharp and W. Tharion**. The effects of gender, team size and a shoulder harness on soldier performance, Part II: A mass casualty simulation. *Int J Indust Ergon* 18: 41-49, 1996.

108. **Rice V.J. and M.A. Sharp**. Prediction of performance on two stretcher-carrying tasks. *Work* 4: 201-210, 1994.

109. **Rice, V. J., Sharp, M. A., Nindl, B. C., and Bills, R. K.** Prediction of two-person team lifting capacity. Santa Monica,CA: Human Factors and Ergonomics Society, 1995, 645-649.

110. **Rieger W.** *Army Accessions Command Standardized Physical Training Guide* (Technical Report). Ft Benning, GA: US Army Physical Fitness School, 2003.

111. **Robertson D.W.** *Documentation of muscularly demanding job tasks and validation of an occupational strength test battery (STB)* (Technical Report). 1992.

112. **Selan, J. L.** Effect of psychosocial variables on maximum acceptable weight of lift. In: Proceedings of the Human Factors Society 22nd Annual Meeting, 1986, 230-233.

113. **Selan, J. L., Halcomb, C. G., and Ayoub, M. M.** Psychological variables effecting lifting capacity: A review of three studies. Asfour, S. S. North Holland: Elsevier Science Publishers B.V., 1987, 987-993.

114. **Sharp D.S., J.E. Wright, J.A. Vogel, J.F. Patton, W.L. Daniels, J. Knapik and D.M. Kowal**. *Screening for physical capacity in the U.S. Army: an analysis of measures predictive of strength and stamina* (Technical Report) 8/80. Natick, MA: U.S. Army Research Institute of Environmental Medicine, 1980.

115. **Sharp M., M. Bovee, B. Boutilier, E. Harman and W. Kraemer**. Effects of weight training on repetitive lifting capacity. *Med Sci Sports Exerc* 21: S87, 1989.

116. **Sharp M., D. Pietila, J. Alemany, K. Rarick, J. Staab, B. Nindl, W. Kraemer, B. Spiering, D. Hatfield and C. Maresh**. Comparison of Three Training Programs for Improving Repetitive Lifting Task Performance in Women. *Med Sci Sports* 38: 2006.

117. **Sharp M.A., E. Harman, J.A. Vogel, J.J. Knapik and S.J. Legg**. Maximal aerobic capacity for repetitive lifting: comparison with three standard exercise testing modes. *Eur J Appl Physiol* 57: 753-760, 1988.

118. **Sharp M.A., E.A. Harman, B.E. Boutilier, M.W. Bovee and W.J. Kraemer**. Progressive resistance training program for improving manual materials handling performance. *Work* 3: 62-68, 1993.

119. **Sharp M.A., J.J. Knapik and A.W. Schopper**. Energy cost and efficiency of a demanding combined manual materials-handling task. *Work* 4: 162-170, 1994.

120. **Sharp M.A. and S.J. Legg**. Effects of psychophysical lifting training on maximal repetitive lifting capacity. *Am Ind Hyg Assoc J* 49(12): 639-644, 1988.

121. **Sharp, M. A., Patton, J. F., and Vogel, J. A.** A data base of physically demanding tasks performed by U.S. Army soldiers. Santa Monica, CA: Human Factors and Ergonomics Society, 1996, 673-677.

122. **Sharp M.A., J.F. Patton and J.A. Vogel**. *A database of physically demanding tasks performed by U.S. Army soldiers* (Technical Report) T98-12. Natick, MA: US Army Research Institute of Environmental Medicine, 1998.

123. **Sharp, M. A., Rice, V. J., Nindl, B. C., and Mello, R. P.** Maximum acceptable load for lifting and carrying in two-person teams. Santa Monica, CA: Human Factors and Ergonomics Society, 1995, 640-644.

124. **Sharp M.A., V.J. Rice, B.C. Nindl, R.P. Mello and R.K. Bills**. Predicting team lift and carry performance from muscular strength, power and body composition. *Med Sci Sports Exerc* 30: 1788, 1998.

125. **Sharp M.A., V.J. Rice, B.C. Nindl and T.L. Williamson**. Effects of team size on the maximum weight bar lifting strength of military personnel. *Hum Factors* 39: 481-488, 1997.

126. **Sharp M.A., V.J. Rice, B.C. Nindl and T.L. Williamson**. *Maximum team lifting capacity as a function of team size* (Technical Report) 2/94. Natick,MA: US Army Research Institute of Environmental Medicine, 1993.

127. **Shoaf C., A. Genaidy, W. Karwowski, T. Waters and D. Christensen**. Comprehensive manual handling limits for lowering, pushing, pulling and carrying activities. *Ergonom* 40: 1183-1200, 1997.

128. **Snook R.H., A.R. Campanelli and W.J. Hart**. A study of three preventive approaches to low back injury. *J Occup Med* 20: 478-481, 1978.

129. **Snook S. and V. Ciriello**. Maximum weights and work loads acceptable to female workers. *J Occup Med* 16(8): 527-534, 1974.

130. **Snook S., C. Irvine and S. Bass**. Maximum weights and work loads acceptable to male industrial workers. *Am Ind Hyg Assoc J* 31: 579-586, 1970.

131. **Snook S.H. and V.M. Ciriello**. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonom* 34(9): 1197-1213, 1991.

132. **Stevenson J.M., J.T. Bryant, G.M. Andrew, J.T. Smith, S.L. French, J.M. Thomson and J.M. Deakin**. Development of physical fitness standards for Canadian armed forces younger personnel. *Can J Sport Sci* 17(3): 214-221, 1992.

133. **Stevenson J.M., J.M. Deakin, G.M. Andrew, J.T. Bryant, J.T. Smith and J.M. Thomson**. Development of physical fitness standards for Canadian Armed Forces older personnel. *Can J Appl Physiol* 19: 75-90, 1994.

134. **Stevenson J.M., T.J. Smith, J.M. Deakin, J.T. Bryant, H.A. Quinney, J.D. Marshall, R.P. Pelot and P. Campagna**. *Development and validation of Canadian Forces minimum physical fitness standards* (Technical Report). Ontario,Canada: Queens University, 1995.

135. **Taboun, S. and Dutta, S. P.** Prediction models for combined tasks in manual materials handling (CTMMH). In: Proceeding of the 1984 International Conference on Occupatioal Ergonomics, 1984, 551-555.

136. **Taboun S.M. and S.P. Dutta**. Energy cost models for combined lifting and carrying tasks. *Int J Indust Ergon* 4: 1-17, 1989.

137. **Teves M.A., J.E. Wright and J.A. Vogel**. *Performance on selected candidate screening test procedures before and after Army basic and advanced individual training* (Technical Report) TR13/85. Natick, MA: U.S. Army Research Institute of Environmental Medicine, 1985.

138. **Ulin S.S., D.B. Chaffin, C.L. Patellos, S.G. Blitz, C.A. Emerick, F. Lundy and L. Misher**. A biomechanical analysis of methods used for transferring totally dependent patients. *SCI Nursing* 14: 19-27, 1999.

139. **Unger R. and S. Gallagher**. Lifting in four restricted lifting conditions. *Appl Ergonom* 237-245, 1990.

140. **van der Doelen L.H.M., M.J. van Dijk, T. Visser and B.J. Veenstra**. *Physiological aspects of the military task lifting* (Technical Report) 96-104. Utrecht,NL: Trainingsgeneeskunde & Trainingsfysiologie, 1996.

141. **VanNostrand S.J., M.E. Thompson and G.J. Captain**. *Evaluation of the Military Entrance Physical Stength Capacity Test (E-MEPSCAT)* (Technical Report) CAA-SR-85-23. Bethesda,MD: US Army Concepts Analysis Agency, 1985.

142. **Visser T., M.J. van Dijk, L.H.M. van der Doelen and B.J. Veenstra**. *Physiological aspects of the military task load-carrying* (Technical Report) 96-105. Utrecht,NL: Trainingsgeneeskunds & Trainingsfysiologie, 1996.

143. **von Restorff W.** Physical fitness of young women: carrying simulated patients. *Ergonom* 43: 728-743, 2000.

144. **Waters T.R., V. Putz-Anderson, A. Garg and L.J. Fine**. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonom* 36(7): 749-776, 1993.

145. **Welbergen E., H.C.G. Kemper, J.J. Knibbe, H.M. Toussaint and L. Clysen**. Efficiency and effectiveness of stoop annd squat lifting at different frequencies. *Ergonom* 34(5): 613-624, 1991.

146. **Wenger H.A.** *Army Fitness Manual* (Technical Report) B-GL-382-003/FP-001. Toronto, CA: Canadian Armed Forces, 2001.

147. **Williams A.G., M.P. Rayson and D.A. Jones**. Resistance training and the enhancement of the gains in material-handling ability and physical fitness of British Army recruits during basic training. *Ergonom* 45: 267-279, 2002.

148. **Williams A.G., M.P. Rayson and D.A. Jones**. Effects of basic training on material handling ability and physical fitness of British Army recruits. *Ergonom* 42: 1114-1124, 1999.

149. **Williams C., J. Petrofsky and A. Lind**. Physiological Responses of Women During Lifting Exercise. *Eur J Appl Physiol* 50: 133-144, 1982.

Appendix A: Load Limit Recommendations

A.1 TABLE 12: LOAD LIMIT CALCULATIONS FOR VARIOUS MMH TASKS

Type	Equation	Reference
Lowering	$LOC=W_B*H*V*F*AG*BW*TD$	Shoaf et al., 1997 (127)
Carrying	$CC= W_B *V*T*AG*BW*TD$	Shoaf et al., 1997(127)
Lifting	$RWL=LC*HM*VM*DM*AM*FM*CM$	Waters et al., 1993 (144)
Lifting	$LC=WB*H*V*D*F*TD*T*C*HS*AG*BW$	Hidalgo et al., 1997 (41)

* See appendix A.2 for variable definitions and values

A.2 VARIABLE DEFINITIONS

A.2.1 Table 13: Variables for load limit equations for Shoaf et al. (1997)

Variable	Source	Definition	Notes
LOC	From Eqn	Lowering Capacity	
W_B	From Table	Base Weight	
H	From Table	Horizontal Distance Multiplier *	distance from body with respect to the mid-point between the ankles
V	From Table	Verticle Distance Multiplier	
F	From Table	Frequency Multiplier	
AG	From Figure	Age group multiplier	
BW	From Figure	Body weight multiplier	
CC	From Eqn	Carrying capacity	
T	From Table	Travelled distance multiplier	
TD	From Figure	Task duration multiplier	

* Figures and tables are not included here, but can be found in the original reference

A.2.2 Table 14: Variables for load limit equations for Waters et al. (1993)

Variable	Source	Definition	Notes
LC	=23	Load Constant (kgs)	
HM	=25/H	Horizontal multiplier	H=horizontal distance of hands from midpoint between the ankles (cm)
VM	=(1-(0.003|V-75|))	Vertical multiplier	V=vertical distance of hands to the floor (cm)
DM	=(0.82+(4.5/D))	Distance multiplier	D=vertical travel distance between the origin and the destination of the lift (cm)
AM	=(1-(0.0032A))	Asymmetric multiplier	A=angle of asymmetry(degrees)
FM	From Table	Frequency multiplier	F=average frequency rate of lifting measured in lifts/min
CM	From Table	Coupling multiplier	

* Figures and tables are not included here, but can be found in the original reference

A.2.3 Table 15: Variables for load limit equations for Hidalgo et al. (1997)

Variable	Source	Definition	Notes
LC	From equation	Lifting Capacity (kg)	
WB	From figure	Base Weight (kg)	
H	From figure	Horizontal distance factor (cm)	Distance away from the body with respect to the mid-point between the ankles
V	From figure	Vertical distance factor (cm)	Distance from the floor to the hands at the origin of lift
D	From figure	Vertical travel distance factor (cm)	Distance of the hands between the origin and the destination of lift
F	From figure	Lifting frequency factor (times/min)	
TD	From figure	Task duration factor (h)	
T	From figure	Twisting angle factor (°)	
C	From figure	Coupling factor	
HS	From figure	Heat stress factor (°C wet bulb globe temperature)	
AG	From figure	Age factor (years)	
BW	From figure	Body weight factor (kg)	